MICRO-REENTRY-CAPSULE-2 (MIRKA2) REXUS

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ABSTRACT

The Micro-Re-Entry-Capsule-2-REXUS (MIRKA2-RX) student experiment is a precursor project for the CubeSat Atmospheric Probe for Education (CAPE) at the Institute of Space Systems (IRS) of the University of Stuttgart. CAPE is a CubeSat system, which shall allow a miniature capsule to perform a re-entry to qualify new ablator materials and to assess a respective aerothermodynamic data base. MIRKA2-RX is intended for the validation of the capsule's flight behaviour and to ensure the functionality of the electrical and communication system. The experiment is segmented into three components: The first segment is the capsule, which is a version of the later flight model, containing pressure, temperature, acceleration and radiation sensors. A dummy heat shield will be used, as the expected temperatures will not exceed critical levels during this suborbital return.

The second segment is the newly developed ejection-mechanism. It is designed to perform a reliable and simple ejection of the capsule using pyro cutters.

The third segment is a replica of the electric system of the capsule, which will reside within the experiment in the REXUS rocket during the entire compartment flight. It is used as a backup system in case of communication malfunction and if the capsule is irretrievable. This data can be used to evaluate the performance of the electric system independently.

When the sounding rocket reaches its apogee, the capsule will be ejected. During its return to Earth, it will collect and transmit data generated by the sensors. After its impact, it is attempted to retrieve the capsule and to extract additional data stored on board.

1. INTRODUCTION AND MOTIVATION

The MIRKA2-RX experiment is an experiment executed by students to validate the flight behaviour, the communication and electronic system of the MIRKA2 capsule [1] and the specially developed ejection-mechanism LOTUS (Low Orbit Technical Unit Separator) of the of the nanosatellite project CubeSat Atmospheric Probe for Education (CAPE) [2].

CAPE is an educational project, which helps students develop general system engineering as well as specialized experts skills [3]. The vehicle itself serves as a demonstration and qualification platform for electric propulsion and atmospheric re-entry technology. In addition, its mission scenario (see Fig. 1) provides an excellent basis for a spatial characterisation of Earth's lower thermosphere.

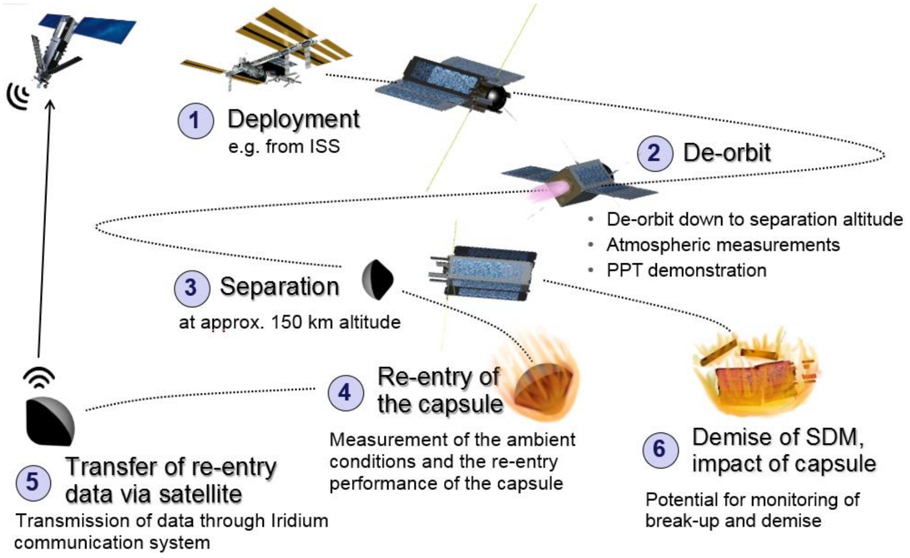

Figure 1. Cape mission scenario

The CAPE system consists of a Service and Deorbit Module (SDM) [4] and the Micro Re-Entry Capsule MIRKA2 (in German: MIkro RückkehrKApsel 2). After the deployment from the ISS at an altitude of 400 km the Pulsed Plasma Thruster (PPT) propulsion system of the SDM reduces the altitude of CAPE down to the separation altitude at 130 km. During the de-orbit manoeuvre, the SDM collects atmospheric data from the lower thermosphere. After the separation of the capsule from the SDM through a separation mechanism, the capsule will perform a re-entry manoeuvre. For the duration of the re-entry, the capsule will collect data of the ambient conditions and the re-entry performance with several sensors. Since no recovery is foreseen, the capsule has to transfer its collected data via the Iridium network to the ground station right after the blackout phase of re-entry. The SDM itself will demise in the atmosphere following the re-entry of the MIRKA2 capsule, which additionally offers an opportunity for monitoring the break-up and demise of the SDM.

Since there is little experience of the flight behaviour of such a small capsule, it is important to validate its in-flight stability and to ensure the functionality of the electrical and communication system.

This validation is conducted by the Mirka2-RX experiment, which will launch on board REXUS-19 in March 2016 and is described in the following.

2. DESCRIPTION

2.1. Mission Scenario

The Experiment will be carried inside of a standard experiment module of the sounding rocket REXUS. After the lift-off signal, the rocket will rise for 26 seconds until burnout as depicted in Fig. 2. At about 64 seconds, the nose cone and motor separate and a jo-jodespin is performed. After 120 seconds, the experiment module will reach the apogee at 80 - 100 km, where the capsule will be ejected. Right after this separation, the electronic system of the capsule will be activated. A satellite link will be established to the Iridium satellite network to transfer most of the data, which are generated by the sensors to the ground station. During the return, the capsule will collect data related to the inflight stability in low Mach regimes. At the same time, the On-Board Control Unit (OCU) inside of the experimental module of the REXUS rocket will activate the mirror system, which is an almost exact replica of the electronic system of the capsule. It serves as a redundancy system for the verification, in case the data transmission of the capsule fails and a recovery thereof is not possible.

After 800 seconds, the experiment module will land and it be retrieved thereafter. The capsule will impact beforehand. Because of the small size of the capsule, a recovery will prove to be very difficult. To increase the chances of locating and retrieving the capsule, it features a radio beacon.

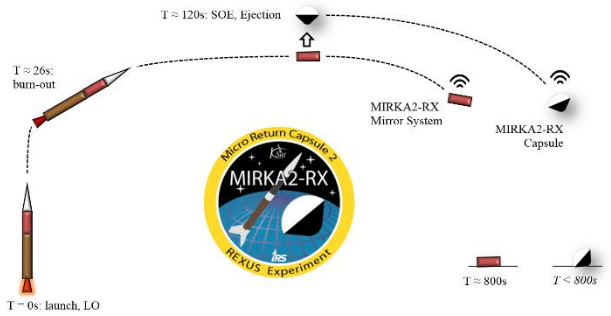

Figure 2. MIRKA2-RX mission overview

2.2. Experimental Setup

As depicted in Fig. 3 the MIRKA2-RX experiment consists of four main sub-systems:

- MIRKA2-RX capsule
- LOTUS ejection-mechanism
- Mirror system of the capsule electronics
- On-board Control Unit (OCU)

The MIRKA2-RX capsule will be placed inside the separation mechanism LOTUS, which is fixed at a mounting structure holding one of the two action cameras as well. This action camera faces directly out of the module and records the separation of the capsule. The second camera is directed to the separation-mechanism itself and records the performance of LOTUS and the separation.

The mirror system and the OCU are mounted inside of the mirror box, which is attached to the base plate of the experimental module. The hatch of the module is fixed by wires. To release the hatch, a pyro cutter, controlled from the rocket itself, will cut the wire and four compression springs will separate the hatch from the experimental module.

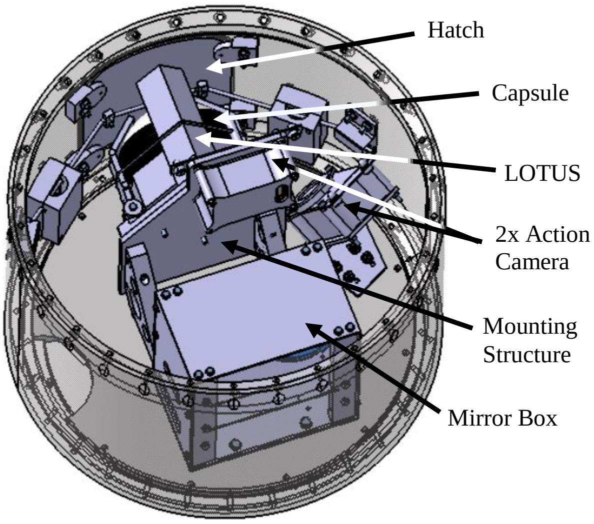

Figure 3. Experimental set-up

Right after the hatch is released, LOTUS will push the MIRKA2-RX vehicle out of the module.

To reduce the cost and development effort, most of the experimental parts are commercial-off-the-shelf components (COTS).

2.3. Capsule MIRKA2-RX

Since the capsule of this experiment is intended to validate the flight behaviour of the MIRKA2 capsule for the CAPE mission, it has the same geometry. The shape is a scaled version of the Re-Entry Breakup Recorder (REBR) [5] with a maximum diameter of 100 mm, in order to fit in one CubeSat Volume Unit (100 x 100 x 100 mm^3). Because of its very compact measurements it has a ballistic coefficient of $\beta = 49\ kg/m^2$ in the continuum flow region [6].

The cross section in Fig. 4 depicts the arrangement of the subsystems inside of the vehicle. They are divided into structure and mechanism, energy system, sensors, communication system and the data-handling system.

The outer structure protects the components inside of the capsule from the loads of the sub-orbital return and provides mechanical stability. It consists of an aluminium tip covered by a dummy heat shield, which stands in for the heat shield material to be used for the MIRKA2 capsule of CAPE. The aft shell is made of the WHIPOX^{TM} ceramic [7] instead of a metallic material to allow for an unobstructed transmission for the GPS- and Iridium transceiver as well as the wildlife tracker. To ensure a stable flight a tungsten alloy weight is placed as close as possible to the nose tip.

In order to guarantee that the capsule will not send any signals during the prelaunch/launch-phase, the deactivation pin pushes the deactivation button to cut of the power supply of the capsule. The pin itself will be pushed by a deactivation rod through a hole in the front cone, which simultaneously serves as a view hole for the thermopile sensor and for the stagnation pressure measurement. To be sure that the capsule is shut down, a buzzer placed inside of the vehicle stops buzzing after the electronics are switched off.

Table 1. Battery service life

		min [h]	nominal [h]	max [h]
Transmitter Off	nominal	3.01	3.78	5.74
	hot case	3.31	4.16	6.32
	cold case	1.68	2.12	3.22
Transmitter On	nominal	1.84	2.01	5.75
	hot case	2.02	5.75	6.32
	cold case	1.03	2.10	3.22

The design of the capsule electronics is depicted in Fig. 5 in the right-hand box. To supply the electronic system with electrical power, the energy system comprise three lithium SAFT LM 17130 primary batteries and a LDO Power Converter. The switch is the deactivation-mechanism mentioned earlier. The batteries are lined up in a serial circuit to generate a voltage of 9V and have a capacity of 0.5Ah each. The LDO Power Converter stabilizes and transform the 9V to 5V. In Tab. 1, it can be seen that for all operational cases the supply duration is far above the total experiment duration of 800s.

To determine the performance of the capsule, it is equipped with several sensors. For the assessment of the flight stability during the separation and the return phase, the IMU (Inertial Measurement Unit) will use an acceleration-, rotation- and a magnetic field-sensor.

A GPS-Receiver is used to track the position of the vehicle and to measure the velocity. Because of the high return velocities of more than 500 m/s and altitudes exceeding 18 km, which are not supported by common GPS devices, a space qualified GPS-Receiver is necessary. Since most space qualified GPS-Modules do

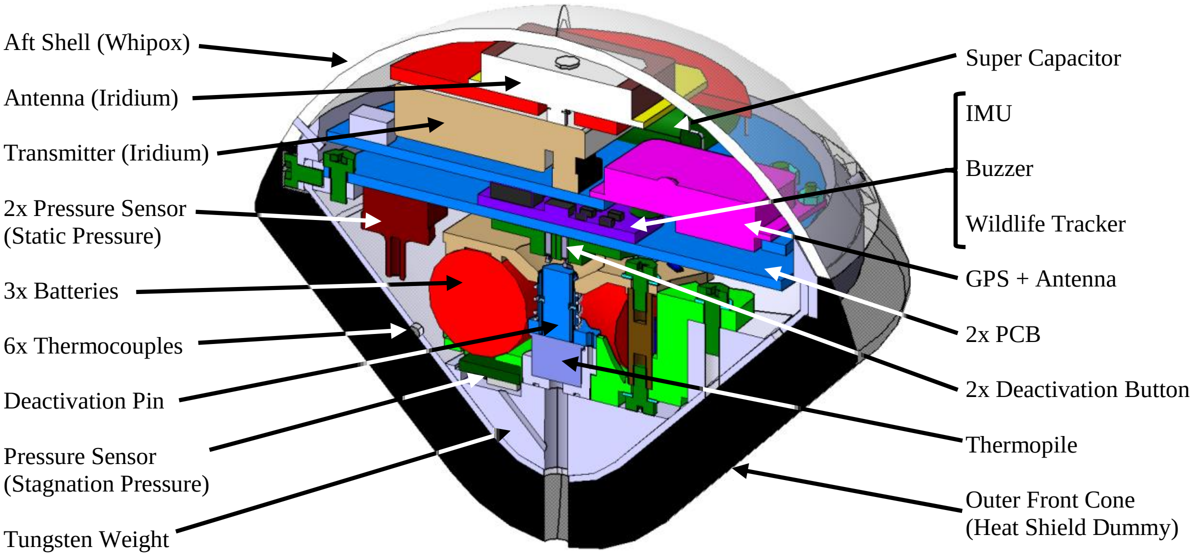

Figure 4. Design of the MIRKA2-RX capsule

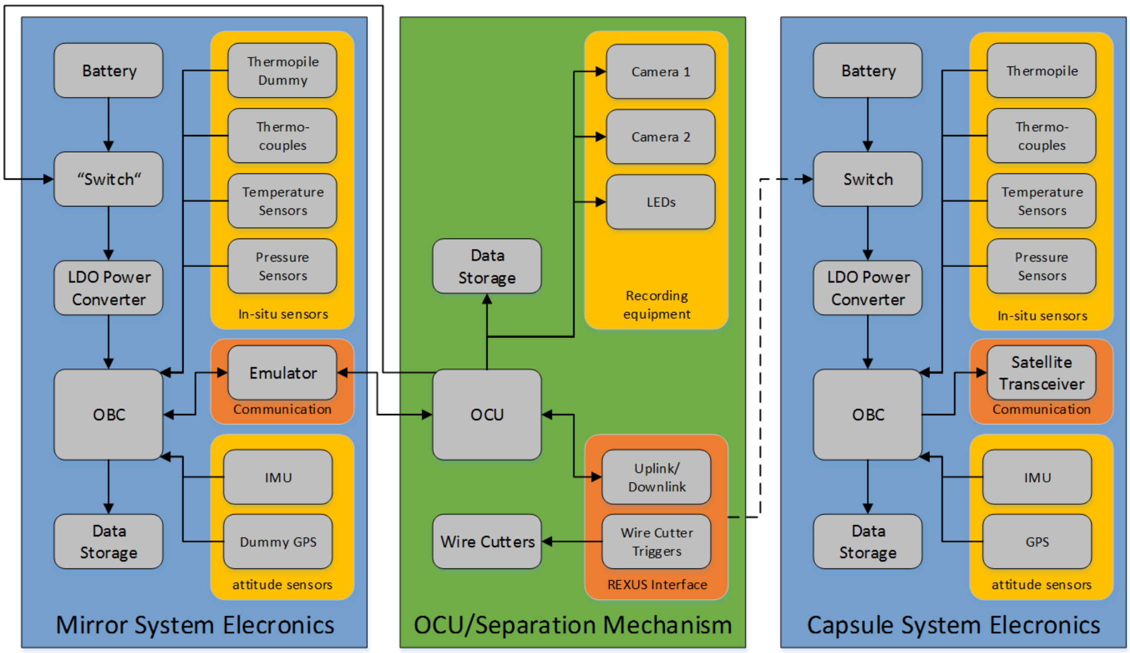

Figure 5. Electronics design overview

not fit inside of the capsule or exceed the budget, the commercially available GPS-Module LS20031 [8] was selected, which is restricted in functionality. Hence, position and velocity measurements are only possible below 18 km altitude.

To analyse the ambient conditions, a pressure sensor, which features an integrated temperature sensor, is placed inside of the capsule. For a wide measurement range, 2 different pressure transductor each adjusted for a specific pressure regime will be operated. In addition there will be a pressure sensor to detect the stagnation pressure at the nose tip.

For the determination of the heat shield performance in the CAPE mission, thermocouples will be placed inside of the ablator in different depths and locations.

Thermocouples are utilized to measure temperatures and heat fluxes through the ablator. The regression rate is indicated through failure of an individual thermocouple. As there no real re-entry manoeuvre is conducted in the MIRKA2-RX project, the thermocouples will only be used to verify the performance of the electronics and the software.

To identify the composition of the plasma and the performance of the ablator for the duration of the re-entry in the CAPE mission, a thermopile detector is placed inside of the deactivation pin and is directed to the hole inside the nose tip.

All the created sensor data will be transmitted via a Quake Iridium 9603 transceiver [9]. It consists of a 1 W transceiver and a patch antenna with 6 dBi gain. To generate the high power required to send the data, a super capacitator is used, which will be charged while the On-Board Computer (OBC) is collecting and preparing thedata for the transmission. Since the possibility of a recovery of the capsule is taken into account, an on-board data storage is included to secure all measured values and housekeeping data. This will increase the chance of obtaining sensor information in case the Iridium uplink fails. To help find such a small vehicle, a wildlife tracker is integrated, which will start to send a signal right before it impacts on the ground. To ensure the functionality of the wildlife tracker after the impact, all electronics to run it and an own power source is cast in plastic material for mechanical damping.

The OCB handles all the sensor data and prepares them for transmission with the Iridium transceiver. It consists of three Arduino Nanos [10]. Each of them has a different task, as presented in Fig. 6. The Sensor/SPI Master Board comprises the six thermocouples and the three pressure sensors and manages the SPI (Serial Peripheral Interface) communication of the sensors and the boards. The IMU Board handles the thermopile, IMU, GPS, Buzzer and the storage of the sensor data on the SD-Card. The Communication Board will gather, process and transmit all sensor data to the Iridium satellite constellation.

To overcome uncertain influences such as space radiation on non-space-qualified hardware, a watchdog mechanism is implemented. Any two microcontrollers can reset the third microcontroller, if they agree that the third one is faulty.

Because of the small size of the MIRKA2-RX vehicle, there is not enough volume to integrate three Arduino Nanos and the harness for all individual components. To implement the microcontrollers and all the parts, a specifically designed Printed Circuit Board (PCB) was constructed. The advantage of this configuration is that the required space is reduced, because the stacking of components can be avoided and less cabling is required.

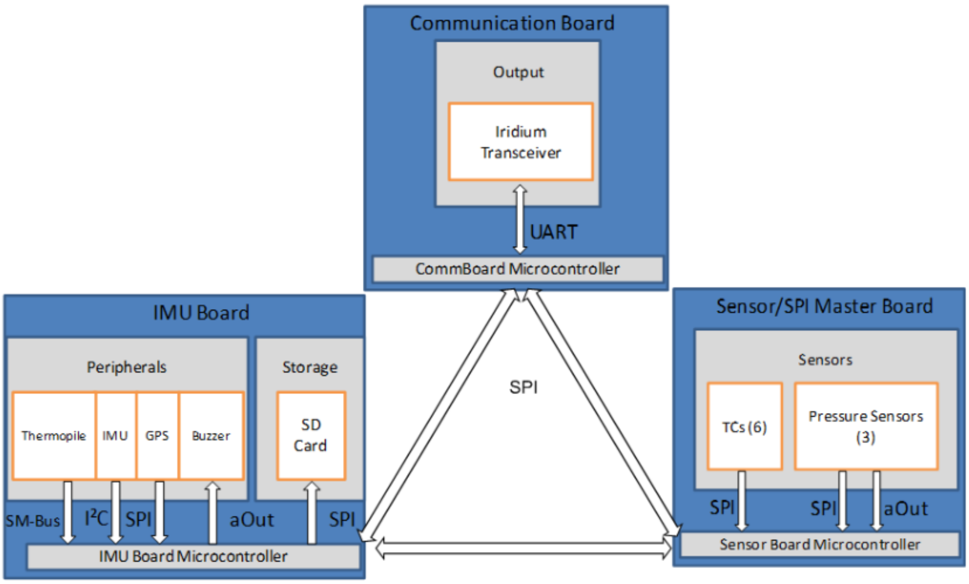

Figure 6. Simplified OBC process overview

This will greatly reduce the complexity of the integration. However, the components can be arranged in any order and the contour of the board is customised to fit the inner volume of the capsule.

2.4. Mirror System

The left-hand box of Fig. 5 illustrates that the mirror system is almost an exact copy of the capsule electronics. Like the capsule, it features its own power source. It only varies in the connection to the electronics of the separation-mechanism, which will send the attained data to the ground station by the REXUS downlink. The Iridium- and GPS-transceiver are replaced by dummy resistors. To simulate an Iridium connection, the OCU emulates the Iridium interface. The activation of the mirror system will be triggered by the OCU, when the experiment starts.

2.5. Separation-mechanism LOTUS

LOTUS is designed to ensure a secure and well-defined separation of the MIRKA2-RX vehicle. It is shown in Fig. 7. It is fixed via a base plate to a mounting structure connected to the bottom plate of the experimental module discussed in chapter 2.2. Two rails are mounted to the base plate in order to fix the position of the carriage and to guide it during the separation phase.

To ensure a good sliding of the carriage Polytetrafluorethylene (PTFE) parts are mounted to the inner side of the rails. The carriage provides a good fit for the nose tip of the capsule and is placed between the two rails. Between the base plate and the carriage, four compression springs are located, which will be held down with the capsule inside of the carriage by two clamps. A wire around LOTUS, holds the clamps together until separation. In the centre of the base plate, the deactivation rod described in chapter 2.3 is fixed. It runs through a hole in the middle of the carriage into the nose tip of the capsule to maintain the deactivation of its electronic system until it will be ejected.

To eject the capsule, the wire around LOTUS will be cut by a pyro cutter to release the two clamps, which will swing open due to torsion springs. Subsequently, the compression springs push the carriage outward after which the capsule is released. At the same time, the deactivation rod releases the deactivation mechanism and the capsule is switched on.

The electronic design of the separation-mechanism is depicted in Fig. 5 in the green box in the centre. As already mentioned in chapter 2.2, the action cameras will record the performance of the separation. They are intended to be activated when the power supply of the REXUS rocket will be switched on. The data of the camera directed towards the hatch will transmit to the ground station via REXUS TV downlink.

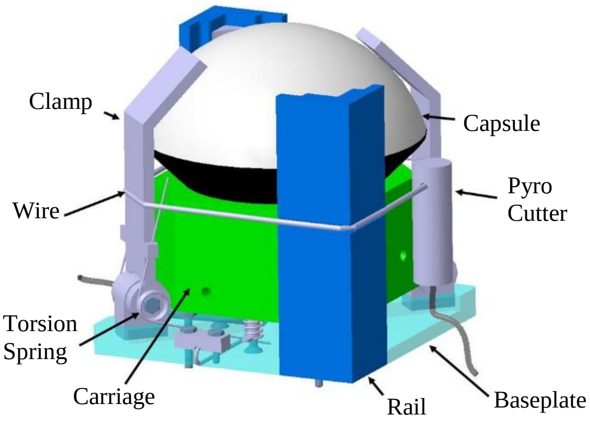

Figure 7. Ejection system in tension state

The data of the second camera directing to LOTUS will be saved on the SD Card located on the OCU, which will be explained in detail in the following section 2.6. The signal to trigger the ignition of the pyro cutter will be generated by a pyro cutter board, which is part of the OCU. The OCU is positioned inside of the mirror box.

2.6. On-Board Control Unit

The OCU consists of one Arduino Mega [12] and one adapter board placed on the top of the Arduino. The Arduino is responsible for the data handling and the transmission of the sensor data of the mirror system as depicted in Fig. 8. To simulate the Iridium transceiver, the sensor data of the mirror system will be acquired with an emulated iridium interface. Subsequently the data will be transmitted via REXUS downlink to the ground station. The adapter board provides the connections to attach all peripheral components and the D-sub connector from the rocket to the Arduino. In addition, it contains all necessary parts to control the action cameras and to run the LEDs, which will illuminate the module for the cameras.

To be able to provide the high current of 1A to ignite the pyro cutter of LOTUS, a dedicated pyro cutter board was designed. It contains several tantalum capacitors, which provide the needed power. They will be charged by a separate power source consisting of five SAFT lithium batteries. A separate power source is needed to separate it completely from the REXUS energy system, because after the ignition of the pyro cutter a short circuit occurs, which may otherwise damage the power system of REXUS.

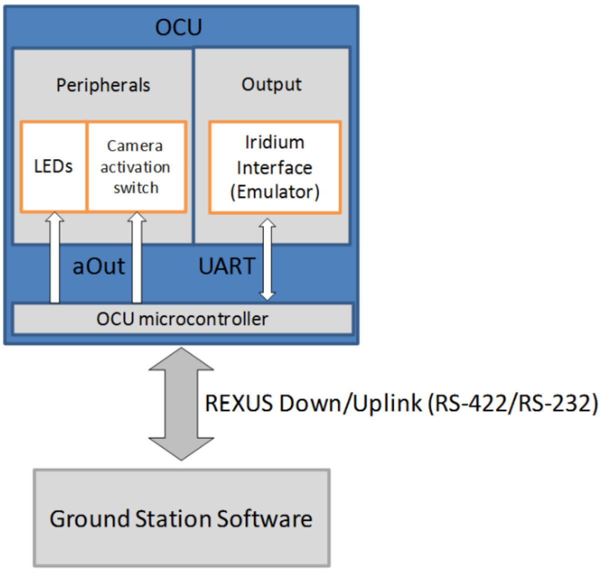

Figure 8. Simplified OCU process overview

3. QUALIFICATION TESTS

Currently, the MIRKA2-RX project is in its qualification phase. Hence, all system elements will be tested for compliance with the requirements.

To qualify the flight stability, a mock-up of the capsule with adjustable centre of gravity was dropped from a crane from a height of 20 m. The movement of the capsule showed that with a centre of gravity at 46% of the capsule's length as seen from the nose tip, the capsule stabilizes itself even if it is dropped with the aft shell pointing downwards.

Furthermore, a vertical wind tunnel test was successfully conducted. Therefore, the capsule was dangled inside the wind tunnel and the wind velocity was raised until the capsule started floating. From the moment it began floating it displayed a stable flight behaviour.

The separation mechanism was already successfully tested under gravitational influence without the pyro cutter as well.

Besides the stability tests and the separation test, some of the electronic components such as the wildlife tracker and the Iridium transceiver as well as some software elements were successfully tested.

In order to test the behaviour of the whole system under the extreme conditions of the launch and in space, the following tests will include a shaker test, a thermal vacuum test and an electromagnetic test.

4. CONCLUSION

The experiment MIRKA2-RX is described. Since within this project the whole ejection system as well as the electronics, software, communication and structure of the capsule was developed, the CAPE project will make a huge step forward to its completion. Aside of the technical advance, the measurement of the flight stability and the stagnation pressure can be used to improve simulations. Furthermore, the acquired experience will be of great help towards the construction of the SDM of CAPE.

For the involved students it is an excellent opportunity to apply their knowledge and to improve their skills in developing and executing spaceflight projects, in order to be prepared better for future challenges in the space industry. In this aspect, the MIRKA2-RX project stands out for its ambitious aim to integrate more than 20 students alongside their studies, which is enabled through the student society called KSat e.V. and a well-structured project management.

5. OUTLOOK

After the experiment, the attained data will be analysed and used to improve the performance of the capsule and the separation system, followed by further experiments to qualify the system and to rise the Technical Readiness Level. Subsequent to the qualification, the SDM of CAPE will be designed, built and tested. For the

qualification process, another REXUS experiment could conceivably be performed.
Should the CAPE mission prove a success, the SDM could also carry other payloads beside the MIRKA2 capsule.

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