PLUTO - THE PAYLOAD UNDER TEST ORBITER

A 6U CubeSat mission for technology demonstration

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Abstract

The PLUTO (PayLoad Under Test Orbiter) mission of the DLR Institute of Space Systems is a 6U CubeSat technology demonstration mission to be launched in 2024. The scope of this paper is to give an overview of the planned mission, the design decisions involved and the hardware to be validated. The hardware to be tested includes the Integrated Core Avionics (ICA), an ultra-wideband wireless camera and a deployable solar array. On PLUTO, ICA includes power handling, a software-defined radio and on-board computer, as well as advanced flight software. The ICA components are mounted in a CPCI Serial Space compatible backplane configuration enabling the use of the same components in CubeSats, SmallSats and standalone applications.

Using experimental components for the primary bus functions poses a considerable risk of losing the mission without any data. To mitigate this risk a commercial OBC and UHF radio are included as bus components to provide data and reconfiguration capabilities in case the experimental components fail. Furthermore, the operational concept of PLUTO is tailored to provide maximum payload data while minimizing the risk of different payloads impeding each other.

1 Introduction

The DLR Institute of Space Systems has historically been involved in the research of all subsystems of a spacecraft, such as avionics, guidance navigation and control (GNC), propulsion and attitude control subsystems (ACS). Thus, there is a regular need for demonstration of the spacecraft (sub-) system research on ground, but eventually also in orbit. Over the past years, various research projects from different departments simultaneously reached a technology level that would eventually require such a demonstration mission. Therefore, PLUTO was designed as a high-risk, high-yield technology demonstration mission for these developments.

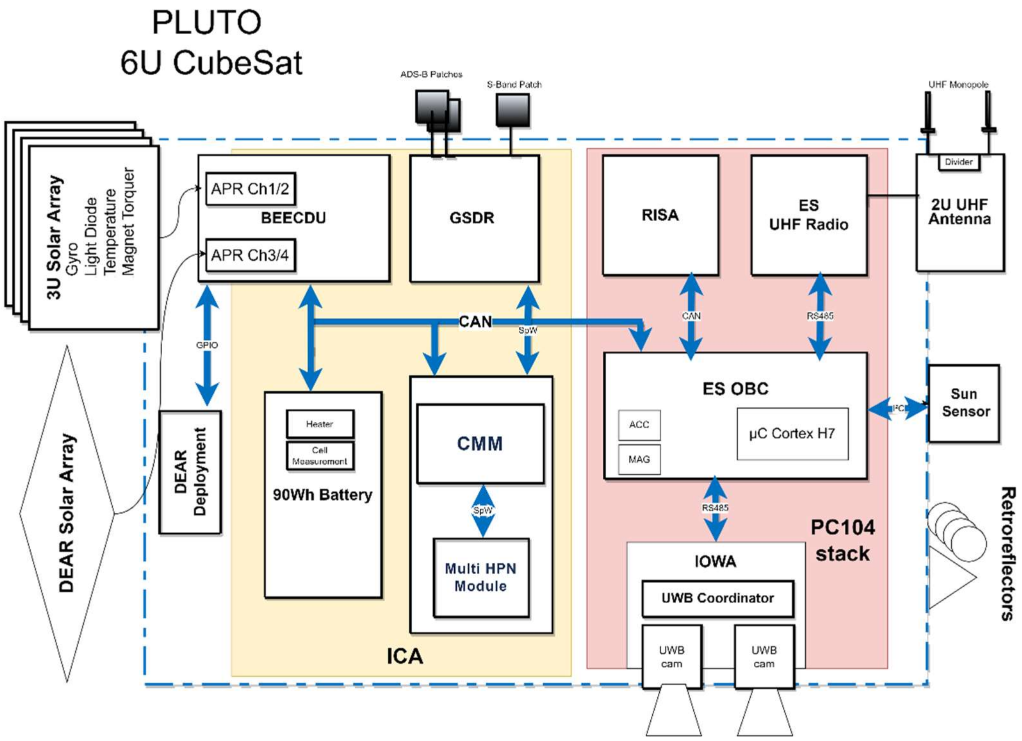

Fig. 1. Overview of the PLUTO system components. Red indicates the components in PC104 standard while the yellow background indicates the cPCI derived components of the Integrated Core Avionics

2 System Design

The following chapter provides an overview on the subsystems and payloads on PLUTO. Due to the experimental nature of most subsystem components, commercial components were added as fallback solutions to maximize reliability. Figure 1 emphasizes this split architecture, since the experimental components are mainly part of the Integrated Core Avionics (ICA) highlighted in yellow while the commercial components are all in the PC104 Stack. However additional experiments are included in the PC104 system for accommodation reasons.

2.1 Integrated Core Avionics

PLUTO's main experiment and key driver for the mission are the Integrated Core Avionics. ICA is an innovative space avionics framework that delivers components for the key avionics subsystems communication, on-board data handling (OBDH), power conditioning and distribution (PCDU) and flight software. ICAs aim is to offer a modular and highly scalable avionics solution that can be adapted to various mission types and spacecraft sizes. As such, ICA realizes the different avionics components in the form of modules, with a backplane architecture based on cPCI serial space. The modules themselves are cartridge-sized modules close to the Eurocard formfactor. This approach makes ICA not only relatively compact, it also allows for a large degree of freedom when it comes to scalability, and dramatically reduces harness due to the backplane architecture. A minimum configuration of a full ICA avionics system (communication module, power module and data handling module) fits into less than 2U of the CubeSat formfactor, making ICA fit for missions as small as a 3U CubeSat. The system can easily be scaled up with additional ICA modules, up to a commercial boxed design for larger-scale spacecraft. The PLUTO mission will be the very first in-orbit demonstration for all of the ICA modules, which are introduced in more detail in the following sections. Figure 2 gives an overview of the mechanical integration of the modules in the CubeSat structure.

Fig. 2. Render of ICA components in the lower part of the 6U structure. Primary structure has been removed for clarity.

2.1.1 Communication

The Generic Software-Defined Radio (GSDR) is a highly versatile, reconfigurable communication subsystem, which has been in constant development at DLR over the past years [1]. It is based on a Zynq-7000 system on chip (SoC) architecture and features up to four independent receive and transmit chains, operable between 70 MHz and 7 GHz. Because the GSDR is using powerful yet technically vulnerable commercial off the shelf (COTS) components, it has been heavily radiation tested and the entire system is both radiation tolerant and fully space-qualified. Because the GSDR is specifically designed for reconfigurability, multiple applications can be executed on the same radio platform with in-orbit reconfiguration. Therefore, its first in-orbit demonstration will include both operational S-Band TMTC communication, as well as other applications such as a multi-channel ADS-B aircraft surveillance mode [2].

2.1.2 On-Board Data Handling

The second ICA experiment is a novel OBDH subsystem which is very close in architecture to DLR's ScOSA research project [3]. Here, PLUTO will be the first demonstration of a system comprised of one reliable node based on a conventional Gaisler GR712 processor, and two high-performance nodes based on Zynq-7000 SoC for more demanding applications. The ScOSA architecture, just as all the other ICA components, follows the philosophy of scalability and is extendable by an arbitrary amount of computing nodes to adapt computing power to the mission's needs.

2.1.3 On-Board Software

The on-board software is one part of ICA with flight heritage. Called OUTPOST (public variant available through [4]), DLR's flight software is an established pillar of the avionics at DLR that first flew on the EU:CROPIS mission. Just as the other ICA components, it is built in a modular way and consists of a flight-proven and hardened code base which offers all core avionics software features such as telemetry and telecommand (TMTC), data management and reporting, housekeeping and all relevant communication protocols.

2.1.4 Wireless Sensor Network

The reduction of harness and design complexity is the goal of a novel ultra-wideband (UWB) network within ICA. Nodes distributed through the spacecraft shall reduce the amount of wiring and connect components through very low-energy and robust wireless connections. This is thanks to the usage of ultra-wideband communication nodes which can be connected to sensors, actuators, avionics components and all other parts of a spacecraft. Precise spatial localization of network nodes is also possible. Previous revisions have already been demonstrated in experiments on the International Space Station [5].

2.1.5 Power subsystem

The PCDU on PLUTO is based on radiation tested COTS components to provide high efficiency. As indicated in 2.2. the use of a large deployable solar array necessitates an efficient conversion stage to limit the power losses in the PCDU. Due to ICAs base on the cPCI standard, the PCDU provides 12V via backplane to all other subsystems. For external consumers, 3.3V, 5V and 12V are provided. For contingency commanding a discrete command interface between the PCDU and the GSDR is implemented. Furthermore, the PCDU provides a passivation function for the solar array regulators and the battery interface. Besides the deployable solar array, a set of commercial CubeSat 3U solar panels are mounted on three sides of the 6U structure to produce power before deployment.
To complete the power system inside the ICA envelope a battery system based on qualified COTS 18650 lithium cells from DLR Institute for Technical Thermodynamics is included.

2.2 DEAR

Apart from ICA, PLUTO will be demonstrating several other DLR technologies. First, the DEAR deployable solar array will demonstrate a 100 W array with an area of roughly 1 m² that is deployed from a 1U CubeSat-size packed shape. This is achieved by using origami-style folding and unfolding mechanisms with flexible membrane-based carrier material, and state-of-the-art solar cells. Figure 3 shows the deployed panel on the CubeSat. The DEAR array is also an enabler for the ICA demonstration, as it will ideally allow a simultaneous operation of all multiple ICA components, which is otherwise challenging to do off the available power density of a conventional 6U solar panel setup. The power aspect of this demonstration is appended by a novel deployment system based on rolled-up tubular booms and a new kind of release mechanism.

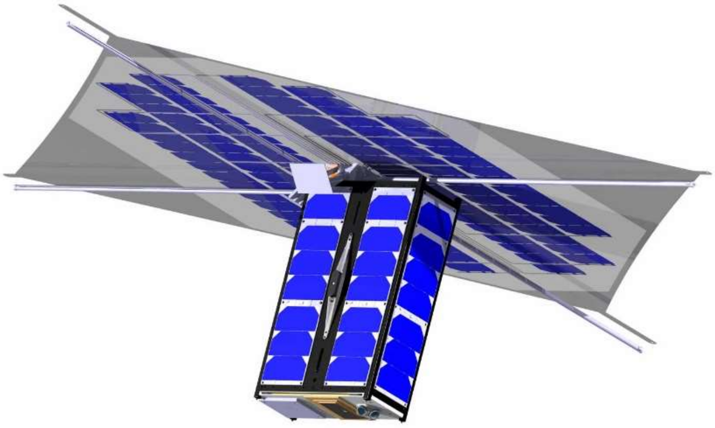

Fig. 3. Render of the overall 6U CubeSat PLUTO with deployed DEAR solar array

2.3 Additional Experiments

Further experiments aboard PLUTO will be a retroreflector experiment called SmartRetro for millimeter-precise satellite ranging (SLR) and even identification from DLR Institute of Technical Physics. Other non-DLR experiments flying aboard PLUTO include an in-orbit experiment of new low-power COTS FPGAs by the Technical University of Hamburg [6].

3 Mission

The PLUTO mission is, by nature of its experiments, a high-risk mission, which, depending on the success of the individual experiments, provides high yield. However, to increase the chances of success, a set of mitigation measures is implemented in the concept of the mission.
Figure 4 shows an overview of the orbital life of PLUTO. After the usual LEOP operations of detumbling and first contact, PLUTO should reach a sun pointing orientation with its body-mounted solar panels. This ensures a positive power budget for the initial commissioning of all systems.

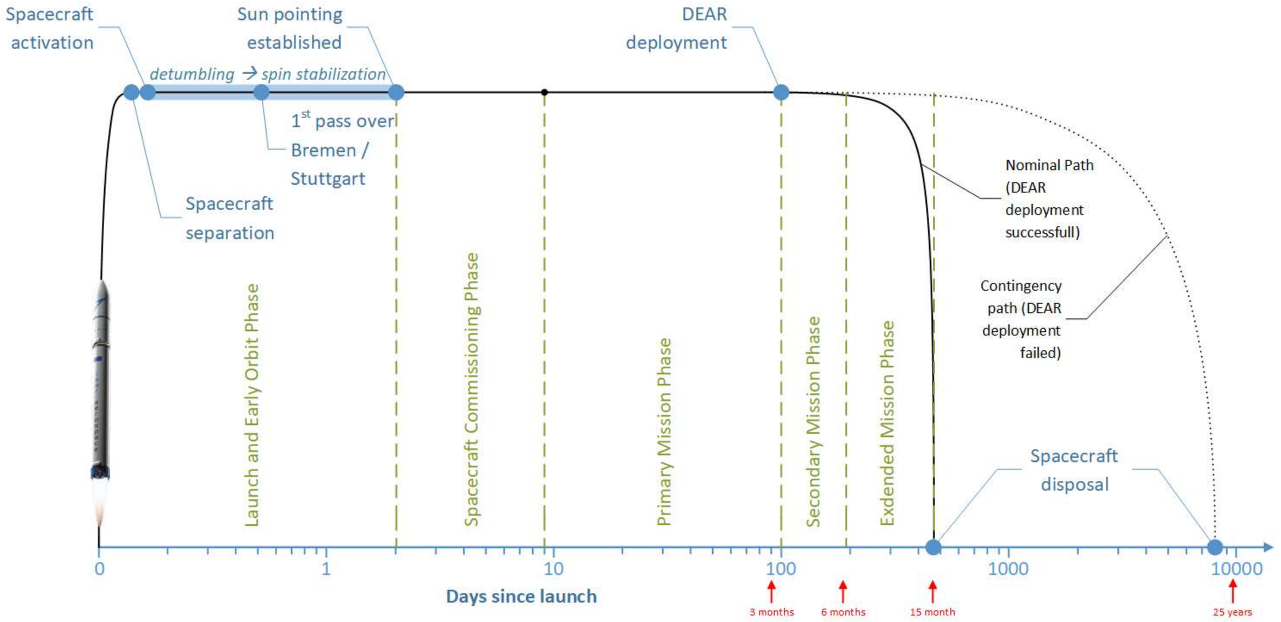

Fig. 4. Timeline of the PLUTO mission showing the adapted mission profile for risk mitigation

Once this is completed, all experiments are conducted in a first low-power phase with limited operating time. This approach ensures all experiments can get a baseline set of data from their systems. Because especially a large portion of the avionics is experimental with no prior flight heritage, PLUTO will make use of commercially available OBC and communication system in parallel to the experimental ones. Especially in this first phase, the commercial components can be used as a baseline to make efficient use of the limited power available.

After this data is collected, the high-risk operation of deploying the DEAR solar array is started. There are multiple risks associated with this. The primary risk is incomplete deployment of the solar cell membrane, resulting in no generation from the membrane while also shading the body mounted solar cells. But even in case of successful deployment, the attitude stability of the system is unclear. The deployment strongly influences the stability of the system, blocks the fine sun sensor and introduces new flexible structures. In case the system deploys successfully and can be steered into a sun-pointing orientation, a secondary mission phase with extended operation of the ICA components is planned. Due to the availability of electrical power, thermal limitations will dictate the operation of the components, but simulations indicate that continuous operation at a power level of around 25W should be possible. Significant operational experience can be gained with the interaction of all subsystems in this phase. However, the lifetime of the mission is limited to around 12 months after deployment due to increased drag with the deployed solar panel.

In case the deployment of the DEAR panel is not successful, further tests will be done on achieving a positive power budget with the remaining solar array. If possible, additional operations will be carried out for as long as useful. Finally, the power subsystem will passivate the system by disconnecting the battery and the solar array from the bus. Even without the added drag, the satellite will deorbit within less than 20 years under worst case assumptions.

4 Conclusion

This paper provides an overview of the experimental components on the high risk PLUTO CubeSat Mission and the operational concept devised to limit the impact of component loss. While a 100% success rate is not guaranteed, at least partial successfult first demonstrations of various new research developments by DLR and its partners can be expected and carrried over to subsequent demonstration missions. Currently, all components are undergoing initial tests and will be integrated for final system tests within Q3 2024. The launch of PLUTO is planned for Q4 2024 on the second flight of an ISAR Aerospace Spectrum Rocket.

5 REFERENCES

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