ERNST: Demonstrating Advanced Infrared Detection from a 12U CubeSat

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ABSTRACT

The ERNST mission will demonstrate complex infrared detection capabilities using a 12U CubeSat platform. ERNST's main payload is an advanced cryogenically-cooled infrared imager that implicates demanding requirements in terms of power demand, heat dissipation, and vibration response for a nanosatellite. The optical bench that integrates optics, a filter-wheel for switching between spectral bands, and the detector-cooler system has been additively designed and manufactured, giving it a bionic appearance and combined with a highly efficient radiator. An onboard radiation monitor and a COTS camera complete the mission payloads. The ERNST 12U platform is based on high-performance CubeSat subsystems for avionics, UHF, and X-band communication, attitude control, and power management. The commercial components are made compatible through a backplane solution. In-house developments include a fast DPU and an autonomous de-orbit dragsail. The platform provides 30 Watt (OAP) and >6U payload volume. After comprehensive environmental and functional testing of the Engineering Model, the Flight Model is currently being integrated. Starting operations in February 2023, ERNST will verify early warning concepts and technology.

INTRODUCTION

Small satellites are currently driving innovation in the satellite sector. Far from being a new invention, satellites with small form factors and masses below 100 kg have been developed for decades by radio amateurs and, later, universities and research institutes. The definition of the CubeSat standard in 1999 marked the beginning of an emergent evolution of small satellites from a niche product exploiting piggyback launch opportunities to the dominant spacecraft type in terms of the number of satellites launched. The launch statistics are meanwhile being driven by commercial providers installing large constellations of small satellites in low Earth orbit. These form a central element of the current transformation of the space industry propagated by its protagonists as New Space. Small satellite technology is developing rapidly in view of the high level of investment in the new space industry. In addition to commercial use, the technological frontier is also being pushed by science missions, reaching out to the interplanetary space.

The reality of a highly dynamic small satellite market leads to the question of whether military applications can benefit from small satellite technology advancement [1]. Although their performance is limited by their smaller size, small satellite constellations allow for global coverage from low altitudes with low data latency. Faster and more frequently available data provides a more up-to-date and, in complementation to existing high-resolution systems, a more comprehensive and heterogenous situation picture. Another important attribute for military utility is system redundancy. The perception of space as a military resource continues to grow in importance, both in terms of exploitation and confrontation. A constellation of satellites is much more difficult to be spotted, manipulated, or even destroyed. Most importantly, they are relatively quick and inexpensive to replace. The low costs and short development times of small satellites are the key enabling features for high responsiveness.

We develop the ERNST mission to demonstrate the potential of small satellites to the German Armed Forces. The challenge here was to implement a complex application such as the detection of missile launches with a cryogenically cooled infrared payload using a CubeSat [2], [3], [4].

THE ERNST MISSION

The ERNST mission is the first satellite mission completely developed by Fraunhofer, which is the largest research organization for applied research in Europe and contributes to space technology on diverse topics. The demonstration of small satellite technology for military utility is the primary objective of the ERNST mission, while the scientific goals are to evaluate missile detection from low Earth orbit and to monitor the orbit radiation environment.

Technology Demonstration

Corresponding to the eponym of the developing institute, the mission name “ERNST” is an acronym that stands for “ExpeRimental Spacecraft based on NanoSatellite Technology”. The ERNST mission intends to evaluate the potential of small satellite technology for military and science purposes for the German Ministry of Defense. The demonstration explores not only the current state of CubeSat technology but also shares the engineering approach. This includes higher risk tolerance with a “validation over certification” approach with a limited budget and a small development team that comes more from the payload side and is extending its capabilities to complete small satellite integration and operation.

ERNST uses a 12U CubeSat platform that is based on commercial high-performance CubeSat components where appropriate parts were available. We tested different CubeSat products during ERNST development for selecting subsystems that meet our requirements in terms of maturity, reliability, and performance. The use of commercially available CubeSat products is an explicit part of the ERNST mission. It is used to minimize the development effort and demonstrate the promises of modularity and standardization.

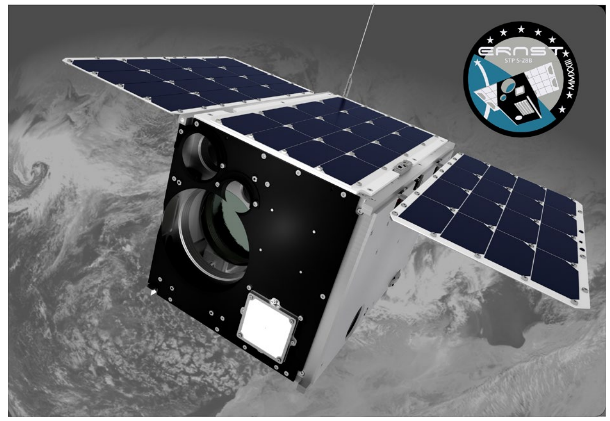

Figure 1: ERNST artistic rendering

When we started the ERNST project, flight-proven CubeSat components were available on the market, but not complete satellite buses that met our ambitious payload requirements. We decided on using the 12U form factor, which was not yet demonstrated but was available in principle for containerized launch. It offered the capacity we needed in terms of payload resource requirements while still being able to rely on CubeSat products. Therefore, we refer to ERNST being a large nanosatellite, even if it exceeds the 10 kg mass limit, but by design it represents the CubeSat approach. Technology highlights developed for the ERNST mission include additively manufactured thermo-mechanical structures, a de-orbit dragsail, and a cryogenically-cooled multi-spectral infrared imager.

Infrared Detection and Tracking of Missiles

The primary science objective of the ERNST mission is the demonstration of infrared imaging concepts and technology for early missile warning. Effective detection and tracking of approaching threats demand fast and reliable image exploitation to ensure sufficient time for automatic initiation of countermeasures. Knowing the infrared signature of both the missile and the terrestrial and atmospheric background is critical for tracking and predicting the flight path. The signature of the missile is composed of the plume heat of the rocket motor and the friction heat of its hull. The contribution of both to the infrared signal characteristics changes with rocket stage operation and flight altitude in dependence on the flight phases, which can be more complex for the new threat of hypersonic boost-glide missiles. Boost phases with several thousand degrees hot plumes can be ideally detected in the short-wave infrared, while the maximum of emissions during gliding phases is shifted to longer wavelengths. Appropriate spectral bands for missile detection are characterized by a high signal-to-clutter-ratio (SCR), i.e. bands in which the missile signature is dominant against a homogeneous background with a low overall

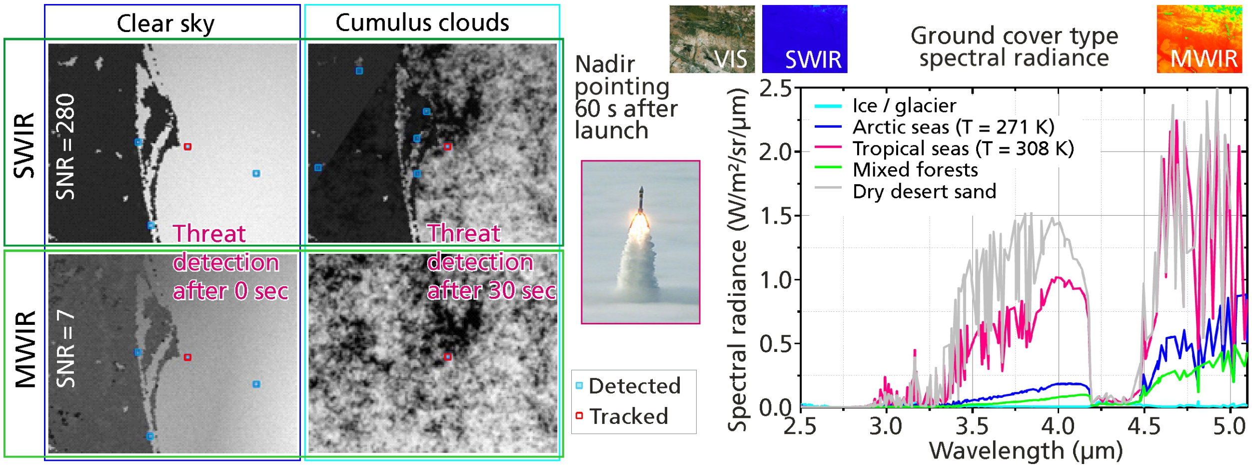

Figure 2: Missile detection and tracking: Scenario simulation for different sky conditions in two spectral bands(left) and background spectral radiance for different cover types (right) from [5], [6].

signal. In general, these lie in spectral regions where the absorption of atmospheric molecules, like carbon dioxide and water vapor, suppresses the background signal. The SCR is optimized by shortening the wavelength through an appropriate cutoff. The ERNST mission will use different infrared channels that enable the detection of a rocket under varying conditions. The basic principle is shown in Figure 2. A missile is detected through the combination of data acquired in the mid-wave infrared (MWIR) and the short-wave infrared (SWIR). The MWIR data allows for detecting the rocket motor plume during launch. The terrestrial background is strongly absorbed in the SWIR data. However, when the rocket has reached a certain altitude, its signature is less absorbed while the background is still at a low level. The same applies if an object is observed against the space background. Thus, a sufficient signal-to-background ratio is ensured for different missile flight phases.

The background signal is composed of the emissions of the Earth's surface (partly absorbed by the atmosphere), the radiance of the atmosphere as well as multiple reflections from clouds. The intensity of the background depends on various factors like ground cover type (cf. Figure 2, right), climate, season, and daytime. Sunlight irradiance reflected from different types of clouds at different altitudes can lead to high background radiance in the sensor field of view. Numerical simulations are used to evaluate the spectral background signature [5]. ERNST will provide a catalog of characteristic background signals in the different spectral channels for validating the simulations and improving the detection methods. The intended 500 km orbit at 97 deg inclination will provide different local times of ascending nodes for observation.

One of the advantages of early warning from low earth orbit compared to geostationary wide-field of view sensors is the higher spatial resolution leading to higher SCR. The compact ERNST main payload provides a ground sampling distance of 75 m and a total ground resolved distance in the expected range of 100 m to 150 m in nadir direction on a 96.0 × 76.8 km² footprint. The infrared signature of the target is detected in only a few pixels. A step-stare approach is used for increasing the observation times in case of target detection or for realizing higher integration times for weak signals in defined regions of interest. Therefore, ERNST is pointing 30 deg ahead nadir in its direction of travel and rotates along its trajectory to track a scene.

Radiation Monitoring

A secondary science objective of the ERNST mission is on-board radiation monitoring. Ionizing radiation is the most severe environmental effect impacting electronics in space. Small satellites are characterized by an extended use of commercial-of-the-shelf (COTS) components with limited knowledge of radiation tolerance. A simple radiation sensing system on a CubeSat footprint with limited resources can help to 1) increase the knowledge of the radiation environment and 2) to provide health-monitoring data for evaluating radiation robustness of components or identifying root cause in case of on-orbit anomalies. The Fraunhofer Onboard Radiation Sensor (FORS) will monitor both single-event upsets caused by high-energy protons and the total ionization dose in the ERNST orbit.

THE ERNST PAYLOADS

ERNST accommodates three payloads: 1) the infrared imaging main payload, which defines the mission and spacecraft parameters, 2) the radiation monitoring

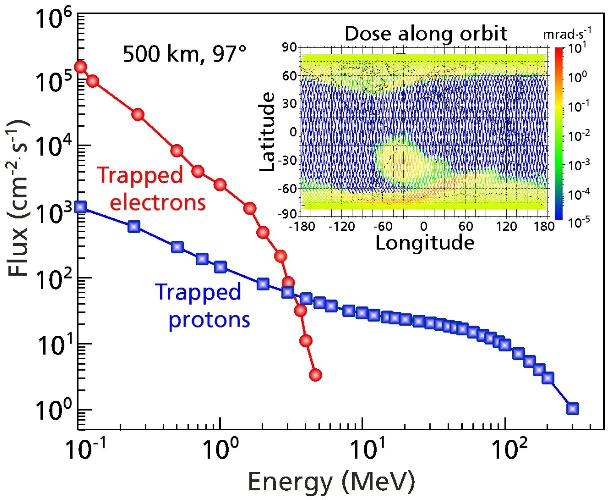

Figure 3: Radiation environment in ERNST orbit

sensor FORS, and 3) a COTS camera in the visual spectrum to be used for georeferencing.

ERNST Infrared Imaging Payload

The ERNST main payload, shown in Figure 4, is a cryogenically cooled multispectral infrared imaging system consisting of the following elements: 1) an infrared objective, 2) a filter wheel, 3) a pyrometer, 4) an infrared detector, 5) a Stirling cryocooler, 6) a data processing unit, and 7) an optical bench with integrated radiator. As for the entire satellite, the approach to the development of the main payload is a combination of commercial components subjected to extensive testing with in-house design solutions.

Comprehensive expertise in designing advanced optics for space missions is available at Fraunhofer, e.g. as demonstrated in our LisR mission [7]. Nevertheless, as the optical apertures for MWIR detection from LEO are quite small, we decided to use a commercial infrared optic for cost reduction. For risk reduction, this optic was extensively tested, including vibration, thermal-vacuum, and radiation. The testing showed that the selected objective is robust against mechanical loads. The focus shift at different temperature levels was found to be in the tolerable range for the aimed resolution. Transmission reduction through radiation induced obscuration of the optic was observed only for significantly elevated gamma-ray doses. For the ERNST Flight Model, the commercial optic was modified with venting holes, fixed focus to infinity, and assembled without lubricants. The baffle for the optic is integrated with the ERNST satellite structure.

The 12U format allowed the integration of a filter wheel for multi-spectral measurements. The wheel stepper motor is based on a flight-proven design from Phytron GmbH. The filter wheel provides eight filter positions, four of which are used for the detection and tracking application. Two further filters are applied for wildfire and water vapor detection. The remaining two filters are used for instrument calibration. This includes an open filter for free space and a reference target. The temperature of the latter is measured by means of a pyrometer. Further components of the filter wheel are a pin puller and the controller board.

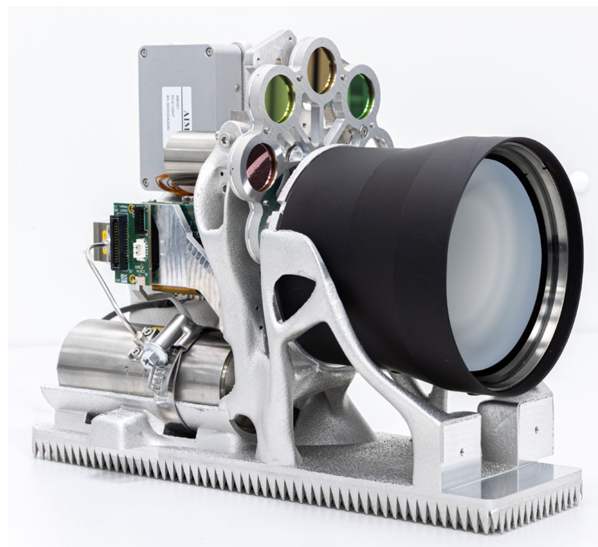

Figure 4: ERNST infrared imager

The central element of the infrared imager is the detector module with an integrated Stirling cooler. ERNST relies on a commercial module from AIM GmbH that was modified for ERNST. The modifications mainly concern the cut-on wavelength of the entrance window and the anti-reflective coating. Given its actual range of application, the detector module was only qualified to MIL standards. Anomalies were observed after vibration testing at ECSS space qualification levels. After a re-work of the cold finger configuration, the module successfully passed the more severe loads.

The detector module comprises a 1.3 megapixel HgCdTe sensor with a spectral range of 2.5 µm to 5.0 µm. The sensor material allows operating it at 95 K or 120 K temperature. This is the main difference from the detector-cooler module we used in the ERNST Engineering Qualification Model (EQM). The InSb sensor used in the EQM is operated at a lower 77 K, demanding higher power demand for cooling provided by a rotary Stirling cooler. The measured vibrations of the rotary cooler would affect the instrument operation, plus it has reduced life cycles compared with a linear split Stirling compressor. The linear compressor has significantly lower vibration levels mainly in the axial direction, which can be aligned with the more insensitive nadir axis. As its cooling capacity is lower compared to the rotary version, only the HgCdTe sensor with linear cryocooler enabled to meet both vibration suppression and power requirements for continuous operation for the ERNST mission.

Infrared image processing, including the tracking algorithm, bad pixel replacement, non-uniformity correction, and lossless image compression, are performed by the Data Processing Unit (DPU), which is based on a flight-proven design [8]. We use a system-on-module (SoM) approach for the DPU hardware [9]. The commercial SoM daughterboard sits on top of a custom base board which mainly provides all electrical interfaces on a small PCB complying with the CubeSat standard. The SoM contains the system-on-chip (SoC) FPGA and the essential peripherals like DDR RAM, flash memory, and power supply. The advantage of the SoM approach is a simplification of the hardware design. It allows the integration of different SoC and FPGAs with minimal changes. For ERNST we use the Xilinx Zynq UltraScale+ MPSoC. The ERNST DPU also controls the integrated detector cooler system, the filter wheel, and provides a CCSDS conforming data stream for downlink.

The ERNST infrared imager components are mounted on an optical bench, for which we exploited the promises of additive manufacturing in terms of designing complex structures with increased functionality [10]. The aim was a lightweight structure that provides a stable support of the imager components while being robust against launch vibrations and thermal loads in orbit. We used a hybrid finite-element based approach for optimizing the topology of the optical bench [11] with respect to 1) the available design space in the satellite, 2) the mechanical interfaces of the imager components, 3) the mechanical launch loads, and 4) the thermal loads generated by the payload. We determined the latter through thermo-graphic measurements of the integrated detector cooler assembly (IDCA). The IDCA emits a considerable part of the consumed input power as heat, which needs to be transferred fast and homogenously to the radiating surfaces facing free space. We printed a three-dimensional pyramidal radiator surface as part of the optical bench. The structured radiator increases the net power emission by 36% compared with a flat surface, thus managing a high-thermal load on a small footprint [12]. The resulting optical bench design has a bionic appearance as shown in Figure 4. We used a selective laser melting facility for manufacturing with optimized process parameters for achieving an adequate microstructure and surface quality. The bench consists of an AlMgSc alloy that gives it high tensile strength and low thermal expansion. The production of the bench included sanding and machining of the interfaces in post-processing. We verified the design through vibrational and thermal testing. Special attention was paid to determine whether small contamination particles detach from the bench surface under loads. We designed, manufactured, and tested different versions of the ERNST optical bench throughout the project.

The infrared imager is complemented by a secondary camera that is used for georeferencing and measuring the temperature emissivity in the visible range. It is a commercial product for which we have determined a ground resolution of 43 m for the ERNST orbit.

Ionization Dose and Single Event Upset Monitor

The radiation detector onboard ERNST is based on using memory chips as sensing elements, i.e. UV-EPROM for measuring the total ionization dose and SRAM to detect high-energy particles. Used before the era of EEPROMS and flash memory, UV-EPROM is non-volatile memory that can be erased by exposing it to strong UV radiation. Ionizing radiation has the same effect through removing charges from the floating-gate transistors. Thus, the received ionizing dose can be directly correlated to the number of deprogrammed bits as shown in radiation testing [13]. The EPROM used as an integrating dose meter onboard ERNST is calibrated with UV light before installation and only powered for read-out with low duty cycle.

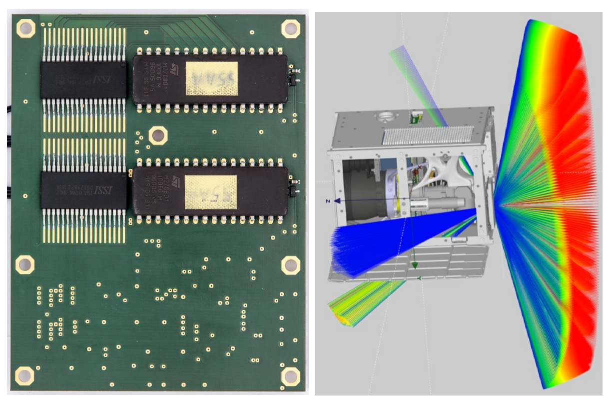

Figure 5: FORS board (left) and sector shielding analysis for one of the chips (right).

Protons and neutrons are known to cause single event effects through depositing electrical charge along their tracks in semiconductors by direct or indirect ionization. Such high-energy protons are detected by FORS by counting the number of induced bit-flips in a static RAM during operation. The used SRAM has undergone comprehensive radiation response characterization and is applied as a single event upset monitor in ESA missions as well [14].

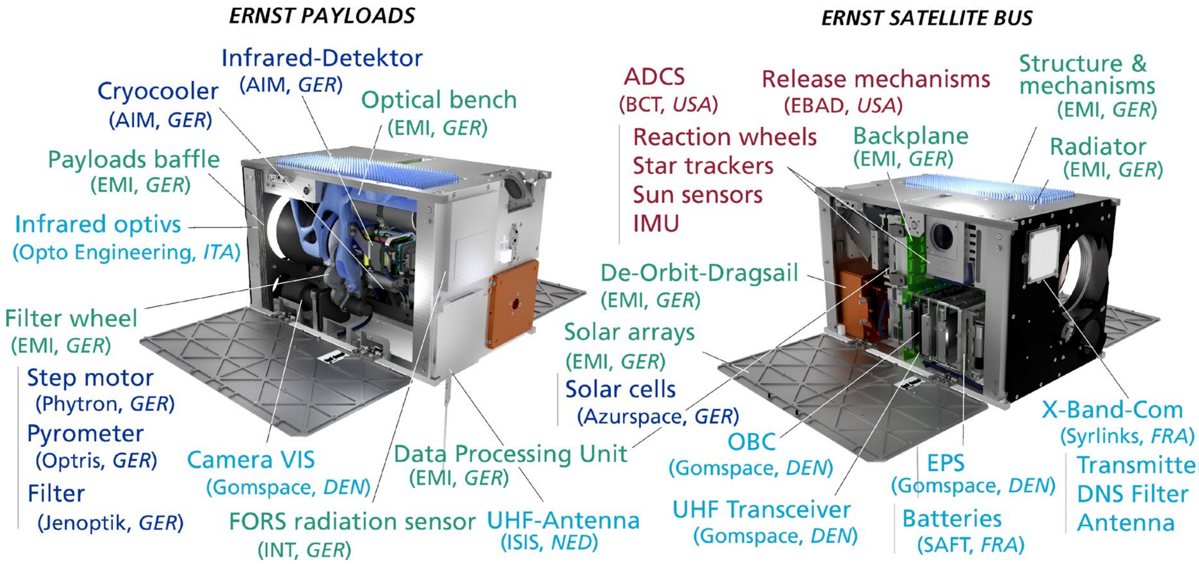

Figure 6: ERNST 12U platform with components and their origin indicated.

Two chips of each type are installed on a CubeSat PCB as shown in Figure 5. FORS is attached to the anti-nadir direction of the ERNST spacecraft. One chip of each type is shielded from free space by an aluminum cover. The thickness of the cover is sufficient to absorb the less penetrative electrons, thus allowing to distinguish the proton component detected with the shielded EPROM from the total ionization dose produced by both electrons and protons in the unshielded EPROM. For the SRAM, the shield allows the sensor to discriminate the heavy particles into two energy bins.

ERNST SPACECRAFT

The ERNST spacecraft is a 12U platform utilizing a $246 \times 246 \times 366\ mm^3$ vehicle size and 22 kg vehicle mass as allowed by the used dispenser. The ERNST platform is modular to the extent that it provides interfaces to CubeSat components from different suppliers as well as a >6U payload volume with additively manufactured supporting structures for flexible payload integration. Figure 6 shows the ERNST platform with components indicated along with their origin. The ERNST spacecraft relies on commercial CubeSat technology, where products that fulfill the functional and performance requirements were available. When testing the ERNST Engineering Qualification Model, we found considerable differences in the quality and design maturity of CubeSat products. Higher priority was given to space heritage and the implemented quality control approach of the suppliers for the ERNST flight model design. We resorted to in-house developments where available commercial products did not meet the design and reliability requirements or where they seemed more cost-effective.

The block diagram of the ERNST nanosatellite platform is shown in Figure 7. The main elements are described in the following where this has not already been done for the payloads above.

Backplane

Compatibility issues inevitably arise when CubeSat products from different vendors are combined. In principle, standardization and modularity can be understood as one of the major benefits of the small satellite design approach, especially for CubeSats. The de-facto CubeSat standard has grown historically, with PC/104 stack connectors mostly used for electrical interfaces and I^2C used as a common communication bus. We consider both not the optimum choice for ERNST and it is no coincidence that more reliable data buses, as well as smaller and mechanically more robust connectors as surface mount device types, become more popular in the CubeSat community [2]. What is more, the pin assignment of the stack connector is underspecified. Besides the common three power rails and I^2C connection, different vendors use their own specifications with a focus on compatibility within their own product family. Only a few vendors allow flexibility through customization of the pin assignment. We overcome those compatibility issues with a backplane solution. The backplane, highlighted in green in Figure 6, is a custom printed circuit board (PCB) that provides PC/104 connections for three vendor-specific stacks. It represents most of the harness for the subsystems. Connected orthogonally at its top site, a small PCB provides interfaces for the electrical ground support equipment for testing and flight preparation.

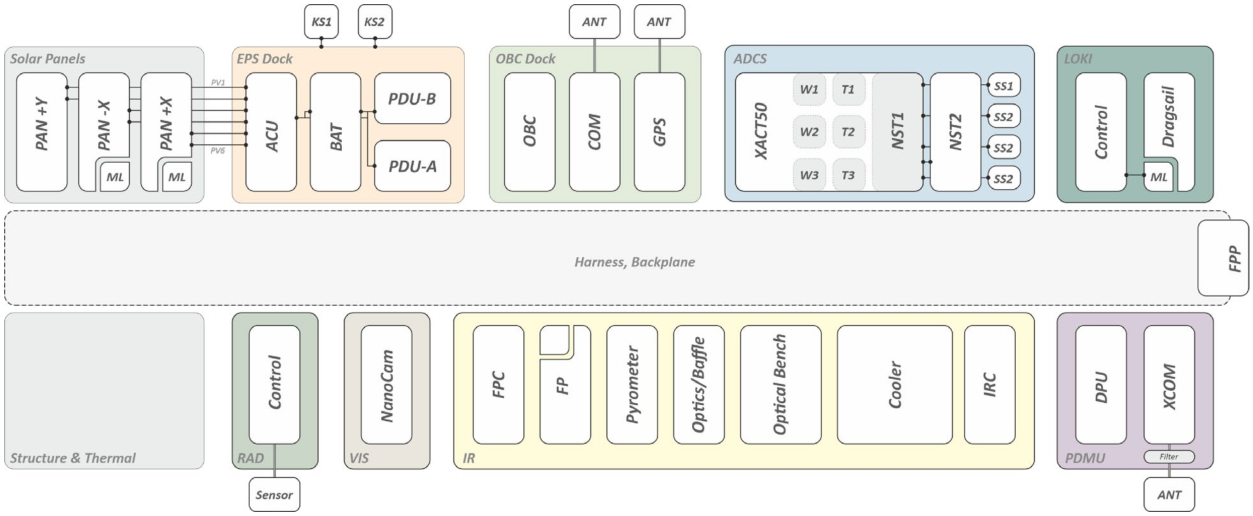

Figure 7: ERNST functional block diagram.

Power

The power subsystem delivers 60 watts peak beginning of life power and 30 watts on-orbit average power for the ERNST mission. We integrated three solar panels, two of which are deployable, with the Azur Space next-generation quadruple-junction solar cell having 32% efficiency. As common for CubeSats, the cell assemblies are glued to PCBs for wiring. These are attached to flat aluminum panels, not necessarily for mechanical robustness but for advantages in both attitude control and thermal control. The implemented electrical power system (EPS) combines different GomSpace products: 1) an array conditioning module with maximum power point tracking, 2) a power conversion and distribution system, and 3) a battery pack with 8 Li-ion cells providing 77 Wh capacity. The EPS provides individually switchable power lines with central overcurrent protection at five different voltage levels for the subsystems. We opted for 24-33.6 V battery voltage for operating the cryocooler with minimal conversion losses.

Avionics and Communications

The onboard computer dock combines the core avionics, i.e. the on-board flight computer, a UHF transceiver, and a GPS module from GomSpace. It uses the CubeSat Space Protocol (CSP) for enabling a client-server-based network architecture for commanding and data handling with the ERNST subsystems. The main data bus implemented is CAN, alongside multiple I^2C busses and serial busses providing a communication interface with components that do not support CAN.

Telecommand/telemetry communication is performed in the UHF band via 1) a GomSpace transceiver that acts as a router in the CSP network, 2) a flight-proven CubeSat antenna from ISISpace, and 3) a ground station at Fraunhofer EMI in Freiburg, Germany, as part of the ground segment. The tape spring CubeSat antenna has redundant thermal knives for the critical automatic deployment after orbit injection. It is operated in monopole configuration with linear polarization and with gain-optimized positioning on the ERNST platform for the low data rate TC/TM communication.

The high-rate payload data is downlinked in the X-band using a transmitter, a deep space network filter, and a patch antenna from Syrlinks. The X-band link provides a 50 Mbps data rate compliant with a CCSDS protocol stack and real-time encryption through the DPU. The ERNST mission relies on a commercial ground station for payload data downlink.

Attitude Determination and Control

The ERNST platform needs precise three-axis determination and control. Particularly, the satellite is required to perform sweeping maneuvers whenever a target is tracked in the field-of-view or the coverage over a region of interest needs to be increased. The attitude determination and control system (ADCS) was one of the critical components, for which we intended to use a fully integrated commercial system to avoid in-house development efforts. We experienced functionality issues with a COTS unit procured for testing with the ERNST EQM. The decision to change the ADCS for the ERNST mission was mainly driven by interference problems of reaction wheels with magnetometers. The ERNST Flight Model uses the XACT-50 from Blue Canyon, which has been successfully demonstrated on ambitious flight missions. It integrates three reaction wheels, three magnetic

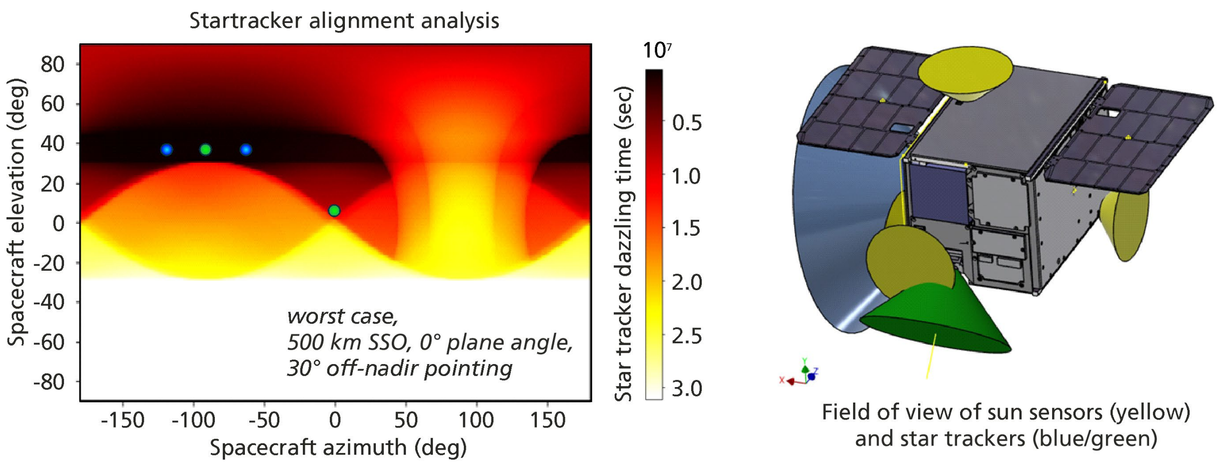

Figure 8: Star tracker positioning analysis example and ADCS sensors field of view

torquers, one star-tracker, and an inertial measurement unit in one ADCS unit to provide 0.007 deg pointing accuracy in fine reference pointing mode. The ADCS is completed by four sun sensors with integrated magnetometers for safe mode Sun pointing. We added an external star tracker to the XACT system for the ERNST platform to minimize star tracker downtimes resulting from stray light exposure from Sun, Moon, and Earth albedo. The limited baffle size of CubeSat star-trackers leads to relatively high Sun exclusion angles and the integrated ADCS products offer less flexibility in star tracker orientation. Figure 8 shows an example of the worst-case analysis of downtimes for a 500 km sun-synchronous orbit with 30 deg off-nadir pointing. Having two star trackers (blue/green) ensures at least one star tracker is not affected by stray light. A further focus when integrating the ADCS in the ERNST CubeSat platform was on verifying the magnetic cleanliness for safe ADCS operation [15].

Structure and Thermal

The 12U CubeSat format enables integrating more advanced payloads for Earth observation tasks. The ERNST platform not only offers the volume and electrical power for the infrared imager but also provides sufficient mass to dampen the vibration excitations of its cryocooler. The relatively high mass allowed per satellite volume is a specific characteristic of CubeSats, which makes lightweight construction unnecessary. The ISISpace QuadPack 12U XL dispenser used for ERNST allows 24 kg maximum satellite mass for a 12 U volume with an extra inch in length. We use the relatively high structural mass margin for 3 mm thick outer panels that provide high thermal mass and some radiation shielding. The ERNST Engineering Model had a modular frame structure for maximizing internal volume and flexibility for accommodation. During integration and testing, it became apparent that the removal and installation of individual components was relatively time-consuming. Therefore, we changed the design of the primary structure for the ERNST Flight Model, which consists of the top and bottom base plates connected by a vertical center rib. This provides higher accessibility and improves the dimensional tolerances of the CubeSat rails at the plate edges, being the mechanical interface to the dispenser. The secondary structures include a backplane structure for the CubeSat stacks, the outer panels, the solar panels mentioned above, and a baffle. The baffle consists of multiple plates with knife-edge cutouts to realize vanes for restricting stray light entering the field of view of the infrared detector.

Different mechanisms are used for the ERNST platform including in-house developments like the solar panel locking hinges, the filter wheel described above, and the de-orbit drag sail described below. For holding down and releasing the deployable structures and mechanisms, we rely on memory shape based mechanisms from EBAD's TiNi product line.

The compact and quite massive structure allows passive thermal control due to the high thermal mass provided. With the increased surface realized with the three-dimensional payload radiator as well as applying adequate surface finish and coating of the outer surfaces, the ERNST platform maintains an operational temperature range of -40°C - +60°C. Thermal modeling and analysis were accomplished using an in-house tool that takes advantage of GPU-based parallel processing for radiative transfer assessment [16]. We paid special attention to identifying heat sources and interfacing them to the satellite structure with thermally conductive links for avoiding high thermal gradients.

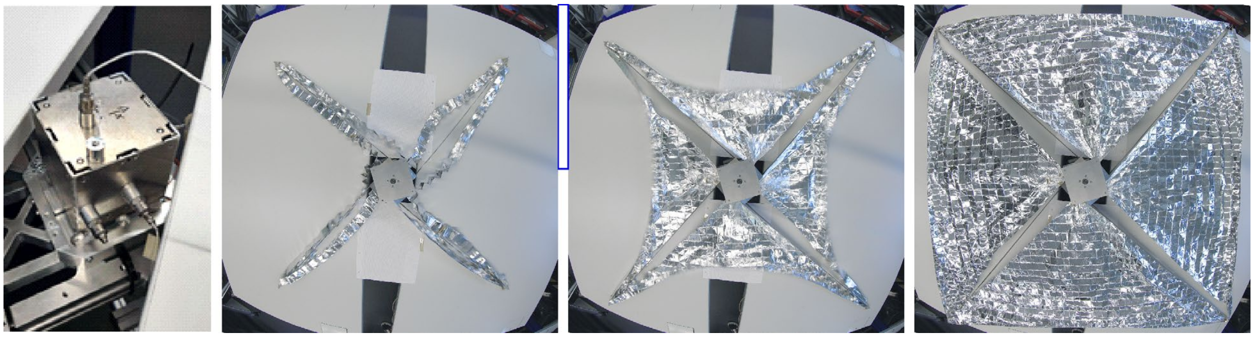

Figure 9: ERNST de-orbit dragsail: Stowed subsystem (left) and deployment testing sequence (right).

De-orbit Dragsail

The threat of space debris impacts increases along with the number of satellites in orbit. Fragmentation events are the major source of the space debris population and collisions are predicted to be the dominant space debris source in the mid-term future. The most effective and pragmatic way to avoid the generation of new space debris is to quickly remove a spacecraft from orbit once its mission is over. The ERNST platform contains a de-orbit subsystem for this purpose. Though ERNST would decay within the required 25 years from its planned 500 km orbit on its own, the objective is to demonstrate a robust and reliable dragsail system at the mission's end for faster de-orbiting. The ERNST de-orbit dragsail is a 2.5 m^2 four-piece sail stowed in a 0.9U sized subsystem. The deployment involves a two-step process. A telescoping mechanism drives the system out of the spacecraft thereby releasing bi-stable tape spring booms that raise the sails as they unfurl. In comprehensive testing, we optimized the design with a central boom spool and individually packed sails [17]. The sail reliably unfolds completely in ground testing without any gravity compensation as shown in Figure 9. The reliability of operation is ensured with an autonomous failsafe control system, which includes a redundant hardware watchdog and a battery. The control system autonomously releases the drag sail after a specific timeout in case of the absence of the external power supply or in absence of a periodic reset signal for the watchdog. Thus, the self-contained de-orbit subsystem would initiate the de-orbit phase even if a commanded release is prevented by the loss of contact or the loss of the satellite.

FROM CONCEPT TO LAUNCH

An important element of the ERNST mission is to develop an ambitious small satellite mission using the current state of technology to demonstrate a responsive and cost-effective scientific and military application. The basic conditions are a small budget, the use of available COTS components where possible, and a small development team. Though the team has a background in space research and payload engineering, ERNST represents the first satellite mission completely developed by Fraunhofer. The team consists of less than ten engineers contributing to ERNST. As common for many small satellite missions, the effectiveness is kept high and the effort is kept low through direct lines of communication and relaxation of traditional space standards and industry practices. The engineering approach foresees extensive testing for risk reduction.

Integration and Test

Since starting the project, we had a special focus on getting hardware in the lab early for development testing of in-house concepts and performance verification of commercial products. Some prototypes were not pursued further when high-performance COTS alternatives emerged as a result of the dynamic market. An example of this is the miniaturized non-pyrotechnic release mechanics with low energy demand. Other commercial components did not meet the expected performance and needed to be replaced for the flight mission. Besides diverse engineering models on the component level, the model flow for the satellite included an Engineering Qualification Model and the Flight Model. The ERNST Flight Model underwent significant design changes, not least caused by the required change of the detector-cooler unit and the ADCS as a result of verification testing with the EQM.

Environmental and functional testing for ERNST could well be based on the extensive development and testing infrastructure existing at the Fraunhofer institutes. Most assembly, integration, and verification activities are carried out by Fraunhofer EMI in Freiburg, Germany. This includes an electronics laboratory and a precision mechanics workshop for manufacturing, a cleanroom for integration as well as an electrodynamic shaker and a thermal-vacuum chamber with Sun simulation for environmental verification. Electronics like the DPU are computer tomography scanned for quality control.

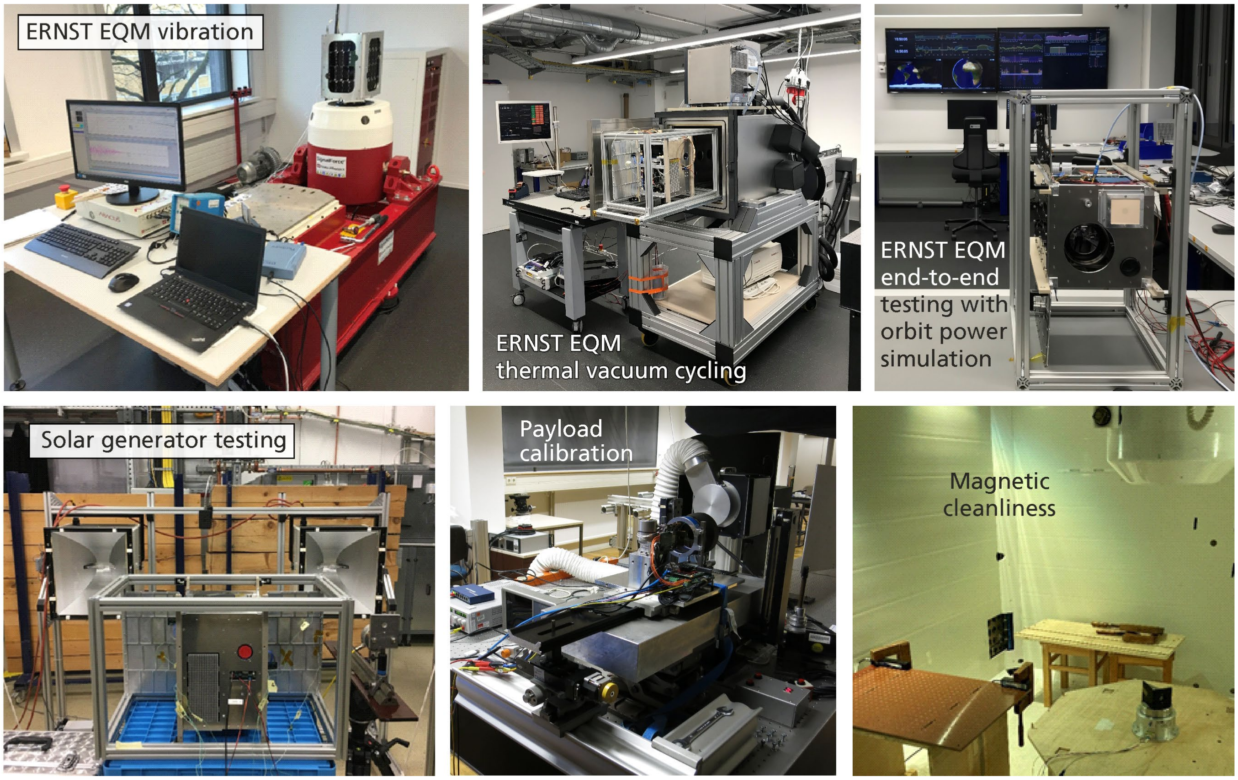

Figure 10: ERNST Engineering Model testing using different facilities.

Besides the test facilities and laboratory equipment, electrical ground support equipment (EGSE) such as solar array simulators and UHF and X-band telecommunication front ends are employed for functional end-to-end testing. We developed a Test and Operation Services Framework for the automation, orchestration, and monitoring of the heterogeneous test infrastructure and EGSE [17]. It is a Python-based middleware, which proved to be very useful for remotely monitoring and controlling comprehensive end-to-end tests during the Covid-19 lockdowns. We plan to extend the Test and Operation Services Framework for the ERNST operational phase with automated, script-based space operations.

Radiation testing was performed at Fraunhofer INT in Euskirchen, Germany. This included verification tests of COTS components like the infrared optic as well as development testing for the FORS radiation monitor. Most of the optoelectronic calibration activities for the ERNST infrared imager are conducted at the Fraunhofer IOSB in Ettlingen, Germany. One highlight of the payload characterization was hardware-in-the-loop testing in the target simulation dome at the Bundeswehr Technical Center WTD 81 in Greding, Germany. There we tested the detection and tracking with the ERNST infrared imager following a simulated infrared signal at the diameter 40 m cupola of the facility.

Another test that is not necessarily standard for small satellites is magnetic cleanliness testing. The widespread use of COTS components for small satellite components increases the risk that permeable materials induce disturbance torques. We measured the magnetic dipole moment of critical ERNST components, like the filter wheel motor or the cryocooler [15]. Figure 10 (lower right) shows the setup of scans, for which the filter wheel motor is installed on a rotary table with a magnetometer in a magnetically shielded room. Such measurements can be conducted at Fraunhofer IPM in Freiburg, Germany. Including the measurement results in a multi-dipole model enabled us to verify that the overall ERNST dipole momentum will not interfere with the ADCS operation.

Status and Path Forward to Launch

At the time of writing this article, the ERNST Flight Model was in the final integration phase, which is to be completed by August 2022. The ERNST Engineering Qualification Model is continued to be used in system end-to-end tests with its avionics updated to the Flight Model configuration. The acceptance testing with the

ERNST Flight model is planned to be started in September 2022. This gives sufficient reserve and time for comprehensive system tests before its delivery in December 2022. ERNST is manifested for the US DoD Space Test Program S28B launch mission. The launch is scheduled for February 2023 onboard Virgin Orbit National System's LauncherOne.

CONCLUSIONS

The ERNST mission will demonstrate the potential of small satellite technology in support of the tasks of the Bundeswehr (German Armed Forces). A multi-spectral cryocooled infrared imager is used to detect and track missiles, whose signatures have rarely been measured from low Earth orbit. ERNST will allow the verification of a space-based early warning concepts and provides comprehensive data of the terrestrial and the atmospheric background in the relevant spectral bands. A secondary payload is used for monitoring the total ionization dose and single events upset in the orbit environment by means of a simple, low resource sensor. The payloads are integrated into the 12U ERNST spacecraft, which is based on commercial high-performance CubeSat components made compatible through a backplane solution and in-house developments. Besides integrating advanced infrared detection in a CubeSat-based small satellite, ERNST includes technology demonstrations like an additively manufactured optical bench with an integrated high-efficiency radiator and a failsafe de-orbit dragsail. The development of the ERNST satellite follows the "validation over certification" approach with a small development team and comprehensive testing including standard environmental verification, radiation and magnetic cleanliness testing, and automated functional end-to-end testing during the different project phases. The ERNST Flight Model integration is on the finishing straight with the launch planned for February 2023.

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