OTTER: A Small Satellite for Responsive Space

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ABSTRACT

The dependence on space-based infrastructure for navigation and communication at sea and on land is greater than ever and provides a significant example of how the failure of a satellite can have far-reaching consequences for civilian and military end users depending on these capabilities. As the likelihood of a collision, technical failure or even an attack on the space architecture increases, the protection of this critical infrastructure in space becomes an even higher priority. This is where the Responsive Space Capabilities come into play which aim at recovering the missing capability in a quick manner. This can be achieved through reconfiguring existing satellites for other purposes, extending existing capabilities or even replacing said satellite with a temporary solution or upgrade. The latter approach requires typically years of development for fully-fledged, long-lived capabilities under current practices because space projects are very challenging and costly in nature. As a middle ground, small satellites could offer a solution for faster, feasible and more flexible approach. To analyze this, the Responsive Space Cluster Competence Centre (RSC³) of the German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt, DLR) conducts the 3U-CubeSat mission OTTER (Optical Traffic Tracking Experiment for Responsive Space). The scope of the OTTER small satellite mission comprises the planning, integration, testing, launch and operation of a small satellite in collaboration with industrial partners. During these phases, current capability gaps related to Responsive Space are identified. Further, research areas to increase flexibility, modularity and to speed up the development in space project are derived. This includes the launch, ground segment and space segments development. The RSC³ identified maritime domain awareness as an internationally relevant security-related application for its CubeSat mission OTTER. The satellite picks up AIS (Automatic Identification System) signals from co-operating ships and takes optical images of the transmitter area. This data is then merged on ground. A European micro launcher will be used to deploy the satellite in a Low Earth Orbit (LEO) at the end of 2024. At the end of the mission, a deorbit maneuver using the electric propulsion system will be conducted after 3 years in orbit.

Together with the integration of the mission into international co-operations, OTTER will make an important contribution to research into Responsive Space and maritime situational awareness. It will demonstrate the potential of CubeSats to provide a timely solution for space-borne capabilities related to maritime security applications.

SMALL SATELLITES FOR RESPONSIVE SPACE

Research on Responsive Space Tasks and Needs

The term "responsive space" denotes the capacity to promptly deliver space-related services and capabilities on demand. Hereby, the exact timeframe depends on the context. In a 2022 call under the European Defence Fund, the EU Directorate-General for Defence Industry and Space (DG DEFIS) challenged the European industry and research organization to study a Responsive Space Systems (RSS) which is able to respond within 72 hours in the following sense: "[...] a resilient and scalable Network of Responsive Space Systems (RSS), fully interoperable, able to launch satellites and commence data delivery".[1] At present, it usually takes at least 9 months or even several years for a payload and satellite to be developed, launched to orbit and to finish its early operation phase. The requirements for Responsive Space vary in nature, but tend to come from crisis situations for civil protection or security. Speeding up the response often comes as a trade-off with increased costs.[2] Crowded orbits, cosmic radiation, component failures, anti-satellite (ASAT) weapons and cyber-attacks are examples for natural and human-caused threats to existing space-based systems. The probability that a satellite will fail increases not only with its age, but also with the population of space.[3] The need to protect, expand or restore this infrastructure in space grows accordingly.

The benefits of Responsive Space are far-reaching: they will increase resilience of the space infrastructure and will hence deter adversaries from interfering with a country's space assets. Developing the concept of a simplified deployment of satellite assets will open up the possibility of realizing a rolling satellite fleet where state-of-the-art technologies can easily be integrated into existing fleets with each new satellite iteration. Responsive Space is also considering the networking of all new systems to create new multi-sensor capabilities and enable interoperability and shared operations. Due to lower cost and shorter development cycles, small satellites offer great possibilities to contribute to these goals.

However, it is not only the infrastructure in space that needs to be considered for Responsive Space Capabilities: The launch segment for the currently mostly fully booked rocket launches from Earth also needs to be made more accessible to be able to rapidly cover any sudden demand that arises. In addition, the ground segment, which has to manage the operation of many satellite missions from as many ground stations as possible, is a decisive factor in the chain for realizing such a capability. The Responsive Space Cluster Competence Center of the German Aerospace Center is researching, analyzing and evaluating this topic and the associated technological, organizational, legal and operational challenges. For this, the small satellite mission "OTTER" (Optical Traffic Tracking Experiment for Responsive Space) is being carried out and will be introduced in the next paragraph.

Research, Analysis and Evaluation with a Satellite Mission

One of the goals of the Responsive Space Cluster Competence Centre is, to find out how the time from demand of a space-based capability to its fulfilment can be shortened and to build the necessary technology base for practical research into Responsive Space Capabilities. The JAPCC journal from summer 2021 states: "An essential element for the RSC³ will be the involvement of users and industry in the research and development (R&D) process. The RSC³ will take on a coordinating role in Germany with the aim of significantly accelerating the technological renewal cycle. To this end, it is necessary to carry out ongoing technology demonstrations and ensure regular technology transfer from research to industry in order to operate the latest state-of-the-art products [...] in space."[4]

Research infrastructure and real development examples are therefore needed to efficiently research, analyze and evaluate current "responsive" satellite developments and not just produce concept studies. For this, the RSC³ has set up the Responsive Space Research and Technology Centre (RSTEC) in Trauen (Germany, Lower Saxony). This is a research hall with clean room laboratories and test facilities for hardware-related research in the RSC³ space and ground segment Figure 1.

Figure 1: Responsive Space Research and Technology Center in Trauen

Learnings from all satellite missions conducted by the RSC³ contribute to this evolving research infrastructure towards a more interconnected, modular test facility for rapid assembly, integration and testing activities.[2]

The first small satellite mission of the RSC³ serves as a demonstrator for the satellite development process up to operational, experimental capability in a short time. The mission is called MSAE OTTER (Maritime Situational Awareness Experiment) where OTTER is the satellite acronym for: Optical Traffic Tracking Experiment for Responsive Space (Figure 2).

Figure 2: 3D-print of the Nanosatellite OTTER

The RSC³ has decided to expand the maritime situational awareness as an experimental requirement that can be met quickly, as this represents a realistic scenario for a contingency or defense case. For this purpose, the satellite is equipped with an optical camera and an AIS (Automatic Identification System) receiver as primary payloads in order to receive vessel signals and localize or verify their position. The combination of data reception and optical verification on the same satellite platform, including its sources, is an interesting concept for future spacecraft as it provides independent, secure and fast access to situational information in maritime regions for the user.

In this context, the RSC³ cooperates with the DLR Institute for the Protection of Maritime Infrastructures, which has confirmed the existence of several relevant observation scenarios: ships in distress, oil spills, illegal, unreported, unregulated (IUU) fishing or smuggling activities that can be detected and reported by satellite AIS receivers and cameras.[5 6]

As this is a scientific experiment, the decision was made to use a standardized satellite form factor, a so-called 3U-CubeSat with the size of 10 cm * 10 cm * 30 cm. Another cost driver for a satellite mission is the slot on a rocket to reach orbit. The space segment of the RSC³ therefore took advantage of the upswing in German micro launchers in 2022 and entered the payload competition organized by the DLR Space Agency for the first flight on the Spectrum rocket from ISAR Aerospace and won a free rideshare on board this rocket for OTTER.[7]

In order to estimate how long the development of such a satellite currently takes in the small satellite industry and how this timeframe can be further shortened, the RSC³ issued a call for tenders in early 2022 inviting European industry to deliver a turnkey 3U CubeSat solution that fulfils the requirement to launch on the first flight of ISAR Aerospace's Spectrum. This tender includes planning, assembling, integrating, testing and transporting the satellite to the launch site and then launching and commissioning the satellite after injection from the rocket in orbit and initial operations. During time till launch, the 3D-printed OTTER model has been used to derive needs for change in the RSTEC test equipment. A special mention deserves the development of a flexible NanoSat mount, which makes it possible to mount 3U CubeSats with different solar panel geometries onto the attitude and orbit control testbed (Figure 3).

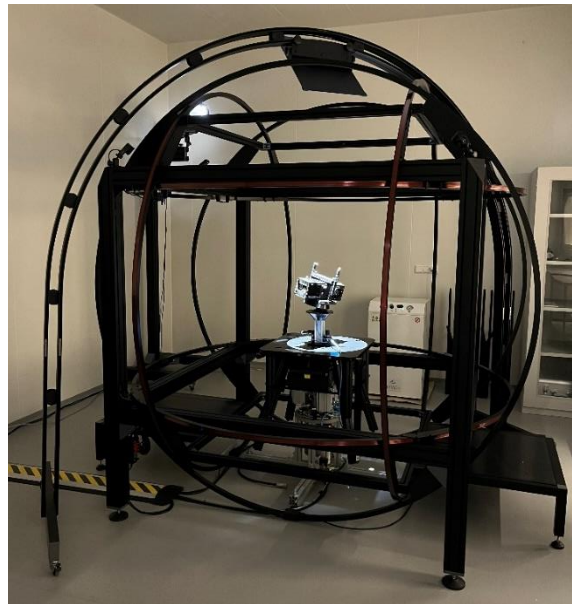

Figure 3: 3D-printed OTTER model on the attitude and orbit control testbed in Trauen

The correct engineering ground support equipment, which enables flexible handling of components in the satellite development process, can help to save many hours or even days and can be easily incorporated into real test and development cycles. Multiple standardized mounting plates on spatially linked environmental test stands, such as the thermal vacuum chamber, the vibration test facility and the attitude and orbit control testbed can save transport times and assembly costs, especially in long and often repeated test cycles. Even the 1:1 sized 3D-printed model of the satellite has proven its value many times, similar to engineering models being used in the satellite development process. Cable routing, fit checking, component assembly and fixture testing for the real satellite, can all be explored safely with such a model beforehand.

THE OTTER CUBESAT

The Europe-wide tender for the turnkey 3U-CubeSat mission OTTER was won by German Orbital Systems from Berlin. It should be noted that in the event of a rapid response requirement, the RSC³ would ideally rely on a stock of modular satellite platforms and components instead of lengthy procurement processes.

Configuration of the Satellite

In an accelerated mission design process, the RSC³ and the satellite manufacturer agreed on the following technical satellite solution, which fulfils all requirements from the tender specifications:

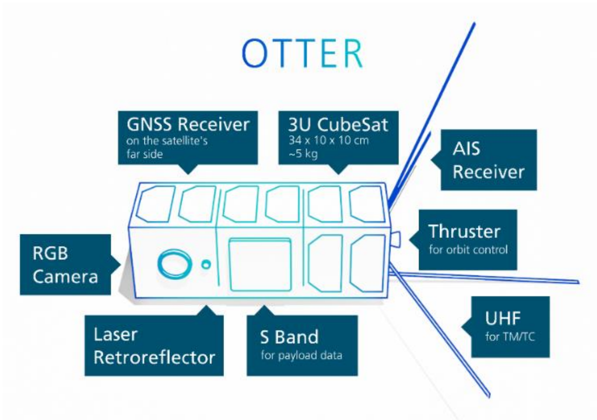

Figure 4: Components of the OTTER

Solar sensors, magnetometers, gyroscopes, a star tracker and a GNSS (Global Navigation Satellite System) receiver are on board to monitor the satellite's position and orbit. Magnetorquer and a reaction wheel system will be installed as actuators. With these elements, an alignment accuracy of 1° is to be achieved so that the camera can also reliably target and photograph larger ships and their wake. The optical camera should achieve a ground pixel resolution (GSD: Ground Sampling Distance) of around 13,75 meters from LEO when the camera is nadir-aligned.

The error of 0.6° in the position knowledge results in a maximum deviation of 1.83 km between the actual location of the ship and the position calculated using the image, satellite altitude and orbital position. Figure 5 shows the error circles and the size of the images taken by the satellite. The detailed view circled in orange has the size of the ±1.83 km error circle and shows two ships with the satellite's 10 m ground pixel resolution. The attitude control data alone is not sufficient to assign the received AIS data to the ships.

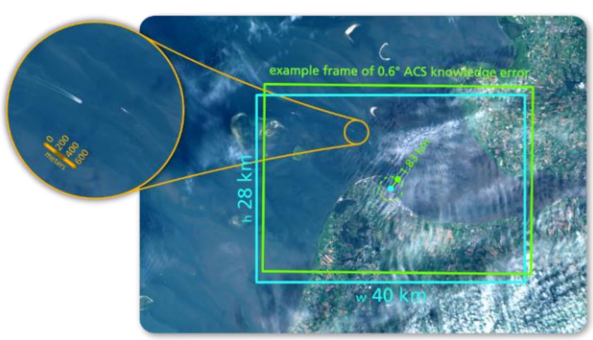

Figure 5: Visibility of vessels above 50m in length on the coast of Cuxhaven. The picture shows 10m GSD, as to be expected from OTTER. (Source: ESA remote sensing)

The more accurate calculation is therefore dependent on additional distinctive features in the image, such as coastlines. These calculations are very demanding for the processing hardware and software. For this reason, they will be carried out on the ground rather than on the satellite during the OTTER mission. The data collected will help to develop the necessary algorithms for on-board processing in future missions. The satellite bus and payloads are powered by fold-out solar panels and batteries.

An S-band patch antenna is used to communicate payload data to the ground and a UHF antenna is used for telemetry and telecommands. The satellite will be operated jointly with the RSC[3] by the satellite manufacturer from Berlin for the first six months. To increase the number of overflights and contacts with ground stations, especially in the early commissioning phase of the satellite, the KSat lite ground station network will be used in addition to the satellite's own ground station.

As a secondary payload, there are two laser retroreflectors on the satellite (see Figure 4 bottom left) from the DLR Institute of Technical Physics, which will be used to carry out laser ranging measurements and tracking with the Mini-Satellite Laser Ranging Station (Mini-SLR) in Stuttgart.

Development of a Resilient Ground Segment for Satellite Operations

During its orbital life time and operations, the OTTER satellite will contribute to the development and testing of a decentralized, hosted, Holistic CubeSat Control Center. This control center allows to conduct satellite operations via a virtual cockpit, that can be accessed independent of location by using a web browser, which connects the user with the ground station and respective interfaces. Only requirement is a working internet connection of the used device. As a clientless remote desktop gateway Apache Guacamole is used. This allows operations without installing any additional software on the client machine. With the implementation of multiple virtual cockpits, the software allows simultaneous flight operation teams to login to their specified satellite operation interfaces. This decentralized concept for satellite operations is particularly interesting in the field of Responsive Space research, because it adds resilience on a strategic, preventive level within the Responsive Space Capabilities.[8]

CONTRIBUTION TO INTERNATIONAL PROJECT ARRANGEMENTS

With its future contribution to maritime security, the OTTER satellite can be integrated thematically into various international projects. The RSC³ plans to contribute the OTTER mission as part of a multinational project for maritime situational awareness using AIS. The focus will be on the development of a low-cost micro-satellite platform for monitoring non-cooperative targets with reconnaissance sensors. In addition, aspects of the operational concept of generating situational awareness by merging various sensor data from other platforms and distributed operation in cooperation with the project partners will be considered. DLR is currently presenting plans for a contribution to this project in order to enter into the international exchange of knowledge in this field and to demonstrate the relevance of rapid-response space-based capabilities. At the same time, the discussion on cross-national interoperability of space infrastructure and cross-sensor data fusion can bring significant added value for security.

[…] During the exchange within this international consortium, it became clear, that an orbital lifetime of at least 3 years instead of 1 year, is required as a contribution. The Spectrum rocket from ISAR Aerospace's maiden flight would separate the satellite at a very low earth orbit, where the propulsion system would have to constantly thrust against the residual atmospheric drag and leave an orbital lifetime of roughly 1 year before the satellite reenters atmosphere to burn up. With increasing importance of this mission and the contribution to international projects, RSC³ decided to swap to the 2nd flight opportunity offered by ISAR Aerospace, launching end of 2024, which offers a higher orbit separation at which the satellite would not require to use the electric propulsion system other than for initiating the de-orbit maneuver after 3 years of operations. In addition, the RSC³ intends to make its OTTER mission available for multinational maritime exercises for space-based reconnaissance. In the past, the contribution of space-based infrastructure to such exercises has been limited, although it can add a lot of value to the situational awareness in under realistic conditions. The imaging and signaling capabilities of OTTER will strengthen the cooperation between the domains and create new realistic exercise scenarios. These include, for example, the failure of terrestrial military reconnaissance capabilities, which must be temporarily compensated for by multi-sensor sources from the air and space, or scenarios in which interoperability between the domains is required, in order to merge complementary information sources and generate a complete situational picture.

ACKNOWLEDGEMENT

The Responsive Space Cluster Competence Center is funded by the German Federal Ministry of Defence.

The RSTEC infrastructure is funded by the REACT-EU package of the European Commission.

References

1. European Union, „European Defense Fund: REACTS Responsive European Architecture for Space," 2023. [Online]. Available: https://defence-industry-space.ec.europa.eu/system/files/2023-06/REACTS-Factsheet_EDF22.pdf. [Visited 04th of June 2024].
2. M. Lehmann, D. Freiknecht und D. Müller, „RSTEC - DAS RESPONSIVE SPACE RESEARCH AND TECHNOLOGY CENTER: ANKNÜPFUNGSPUNKTE FÜR INDUSTRIE UND FORSCHUNG" Bremerhaven, 2022
3. T. Harrison, K. Johnson, T. G. Roberts, T. Way und M. Young, „Space Threat Assessment," 2020. [Online]. Available: https://aerospace.csis.org/wp-content/uploads/2020/03/Harrison_SpaceThreatAssessment20_WEB_FINAL-min.pdf. [Visited 04th of June 2024].
4. W. Jung, T. Vasen und D. Zimper, „Responsive Space for NATO Operations – Part 2," The Journal of the JAPCC, Edition 32, Sommer 2021.
5. R. Churchill und G. Ulfstein, Marine Management in Disputed Areas, the case of the Barents Sea, UK: Taylor & Francis, 2005.
6. T. v. Lierop, „Major operation against migrant smuggling in the English Channel: 39 arrests," Juli 2022. [Online]. Available: https://www.eurojust.europa.eu/news/major-operation-against-migrant-smuggling-english-channel. [Visited 04th of June 2024].
7. „DLR.de," DLR, April 2021. [Online]. Available: https://www.dlr.de/de/bilder/2021/04/mikrolauncher-wettbewerb-rsc. [Visited 04th of June 2024].
8. S. Tholl, A. Ohndorf, et al. "A Holistic Control Center for the Operation of PUS-Based Optical Communication CubeSat Technology Demonstration Missions at the German Aerospace Center". AMOS 2023, 2023-09-17 - 2023-09-20, MAUI, HAWAI.