European citizens rely on space technologies when they use their mobile phones, make financial transactions, take an airplane, watch the weather forecast, or look for the nearest restaurant in their cars. Space-based systems are essential for addressing societal challenges and the implementation of major policy objectives in areas such as environment, climate change, agriculture, transport, development, or security. Any interruption of services [...] can have dramatic economic consequences. The most serious threat to the functioning of satellites and space infrastructures today is the risk of collision with other satellites or space debris.” (Memo from EC, Brussels, 2013).

One major source for new space debris are spacecraft (S/C) which are not removed after the end of their operational lifetime. A few collision events could jeopardize activities in important orbits and
cause significant damage to the infrastructure in space. As a preventive measure to be included in future spacecraft (S/C), TeSeR proposes a Post-Mission-Disposal (PMD) module to be carried into orbit by any S/C to ensure its proper disposal after ending its service lifetime, be it planned or unscheduled due to S/C failure. This module shall be independent of the S/C.

The main objective of TeSeR is to develop a PMD module beginning with the exploration of concepts, up to test an on-ground prototype which demonstrates the main functions. That includes the development and manufacturing of three removal subsystems to be attached to the prototype via a common interface. Additionally, innovative new concepts for the passive control of the attitude of a S/C via the PMD module, a semi-controlled de-orbit concept and multi-purpose concepts complement the technical work. In addition, the analysis of legal aspects, insurance aspects and a survey of the potential market provide the team with important non-technical information thus ensuring a multi-disciplinary picture of the space debris mitigation topic.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

The focus of the first year was on the development of concepts and a functional architecture for a PMD module. That included the critical analysis of space debris mitigation rules, performing mission analysis and defining high-level user and mission requirements and system and subsystem requirements for the PMD module.

The PMD module will serve as a platform on which each of the removal subsystems can be attached individually. The module itself will then be attached on S/C of varying types and sizes. Several architectures of an adaptable PMD module and its subsystems have been developed including a standardized interface to attach the module to different S/C and another standard interface to attach different removal subsystems to the module. Furthermore, operational scenarios have been investigated with different robust, reliable and highly autonomous operation concepts. That includes concepts to detect the hosting S/C’s faulty-and supposedly mission ending–status, to secure the S/C by passivation and to trigger either a safe de-orbit or re-orbit and final disposal of the S/C. In parallel, concepts for three different removal technologies to change the orbit of a S/C have been investigated and are prepared for prototyping with the focus on scalability and standardized implementation to the module via a common interface, i.e.

• solid propulsion
• drag augmentation membrane
• electrodynamic tether.

Concepts for the passive attitude control of a S/C via the module, a semi-controlled de-orbit concept and multi-purpose concepts have been analysed. In addition, the analysis of legal aspects, insurance aspects and a survey of the potential market provided the team with important non-technical information.

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

The TeSeR project takes the first step in the development of a PMD module which is attached to a S/C on ground and which is capable of to perform the PMD for any future S/C at the end of its...
S/C on ground and which is capable of to perform the PMD for any future S/C at the end of its operational lifetime, either the nominal end but also in case of the loss of control of the S/C. With the PMD module the European society and especially the space community (agencies, S/C owners, S/C manufacturers) will have an innovative, reliable and cost efficient tool to increase the PMD success rate to 90%. Consequently, adding new debris to the already existing large debris population is avoided: future S/C will be characterized by higher sustainability, space-based services will feature higher availability and safety, since their self-removal capability keeps relevant orbits free of space debris and thus, ready for additional services that suits EU citizens and all people in the world. This strategy is not only beneficial for the European space industry but for the global market.

The design for variety is a novel approach in space engineering and poses new challenges. TeSeR focuses on modular design for the PMD module itself to deal with these challenges. Also looking further into the needs of future S/C, “advanced” PMD module concepts have been investigated that will use more advanced technology and will operate with higher levels of autonomy thus reducing the workload needed for future S/C removal operators. The design of standardised interfaces that will facilitate the mounting of the module on many types of S/C is also a novel approach. Both, the standard interface and the design for variety allow for the production of similar PMD modules in large numbers, thus reducing their per-unit costs.

An application w.r.t. the standardized interface between PMD module and the S/C could be that it is used as an additional redundant S/C subsystem: in case of an unexpected S/C failure that leaves the S/C with no link to ground, the data and/or electrical interfaces combined with the autonomous status detection abilities and the removal module’s communications subsystem might enable the ground crew to still command the S/C. Thus, the PMD module could be used for S/C recovery before its ultimate removal.

The innovation capacity of the space community is enhanced: Ambitious, future space missions with either scientific or commercial background pose high performance and reliability requirements. These missions could be enabled by providing the capability of safe and highly autonomous operations on-board. Up to now, decisions concerning the recovery from critical faults or the end of S/C operations and, in this case, triggering the self-removal of the S/C are made by ground operators only. The implementation of the proposed enhanced operational concepts and supporting system architecture for on-board autonomy could lower the S/C operator’s workload. Consequently, operational cost of future space missions could be reduced which is essential especially for mega constellations like OneWeb.

The results of our work on resilient status detection capabilities offer great potential for upgrading the traditional approach of fault detection, isolation and recovery (FDIR).

In the long run the PMD module could replace any PMD hardware (e.g. integrated propulsion system). The S/C owner optimizes its S/C for the operational mission and foresees a standardized interface for a PMD module. The PMD module is attached to the S/C via the standardized interface and covers all PMD aspects–thus the S/C owner buys the PMD capability for the S/C. Due to its scalability and flexibility w.r.t. the removal subsystem the PMD module can be produced in serial-production, thus reducing the costs.
Example of the Multi-Purpose Concept
Autonomy levels for the advanced PMD module
Prototype of a solid propulsion system from D-Orbit

Concept draft of the PMD module and its interfaces

No command received from ground

No transmission to ground

Operational or survival temperature range exceeded

Not sufficient power available

error words or flags exist

Change in angle
Detectable symptoms

S/C and AOCS mode and sub-mode other than nominal

triggered FDIR actions

Duty cycles of actuators non-nominal

On/off settings, status and health information of sensors and actuators

Detectable symptoms

Layouts for host S/C with attached drag device

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### Down selection of most promising removal concepts

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Deployment sequence of the SDSS from Aalborg University

Inclination: 98.5 deg; Arc length: 7000 s; Avrg. rel. PD: 0.4%
Orbit trajectory with population density

Guidelines (ISO, ECSS,...) → Project Objectives

User Requirements → Mission Requirements

System Requirements → Subsystem Requirements

Functional Architecture → Design
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