TeSeR – Technology for Self-Removal – First Results of an H2020 Project to develop a Post-Mission-Disposal Module

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ABSTRACT

The goal of TeSeR (Technology for Self-Removal) is to take the first step towards the development of a scalable, flexible, cost-efficient, but highly reliable Post-Mission-Disposal (PMD) module. This module is to be attached to the spacecraft (S/C) on ground and it shall ensure the PMD of the S/C at the end of the nominal operational lifetime or act as a removal back-up in case that the S/C cannot be controlled anymore.

1. INTRODUCTION

THE PMD GAP

One major source of new space debris are S/C which are not removed after the end of their operational lifetime. To mitigate this type of debris, a number of international guidelines and standards, such as ISO 24113, specify that S/C have to be disposed of at end of life with a success rate of at least 90%. An analysis performed by the European Space Agency (ESA) shows that the success rate of PMD in 2013 was in the range of 50% - 60% thus showing a gap to the PMD guidelines.

TESER AIM: CLOSE THE PMD GAP

As a preventive measure to be attached to future S/C on ground, TeSeR proposes a 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 objectives of TeSeR are

- to develop a PMD module by exploring concepts, up to test an on-ground prototype demonstrating the main functions, and
- to develop three removal subsystem prototypes to be attached to the module prototype via a common interface.

Furthermore 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.

2. 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 two standardized interfaces: one to attach the module to different S/C and another one 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.

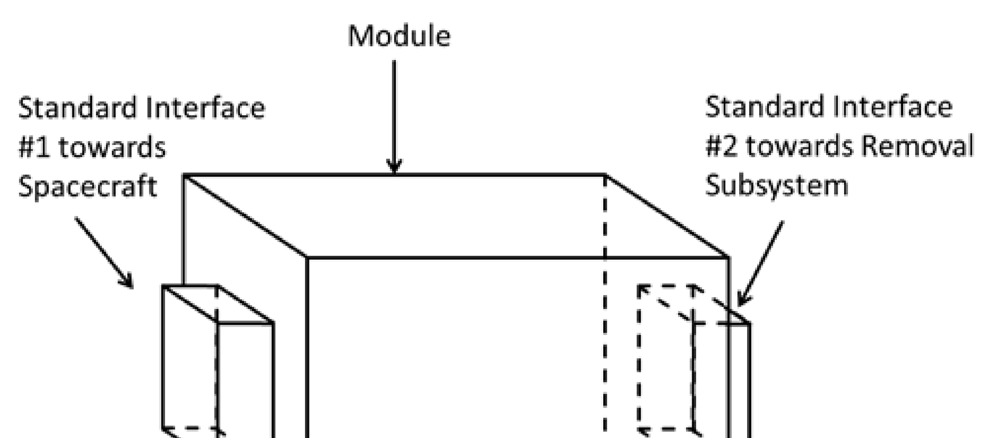

Fig.1. : *Concept of the PMD module with two standard interfaces*

The most basic module concept is fully controlled from ground, thus removal decision and manoeuvre management is ordered by ground station. The module just executes the removal. All relevant information (e.g. S/C orbit, S/C status) are provided without the module. More advanced module concepts with increasing autonomy are shown in the Figure below.

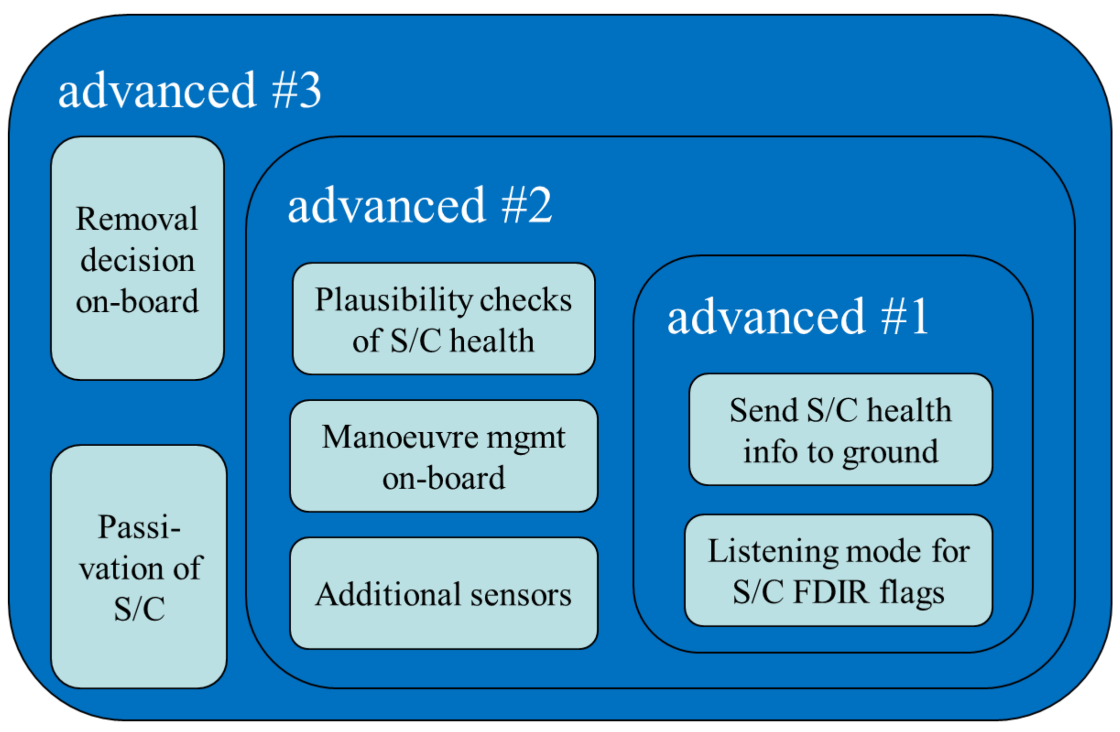

Fig.2. : *Autonomy concepts for advanced PMD modules*

For advanced PMD module concepts an autonomous decision if a S/C has to be removed or not the knowledge about health status of the S/C is of outmost importance. A list of detectable symptoms as shown in Fig. 3 below has been provided within the project that indicate the health-status of the S/C. Different types of sensors with respect to their potential contribution to detect those symptoms of the host S/C on-board the PMD module have been investigated. The sensors have been traded systematically considering their additional benefit, weight and power consumption and the best combination of sensors for the status detection purpose is proposed.

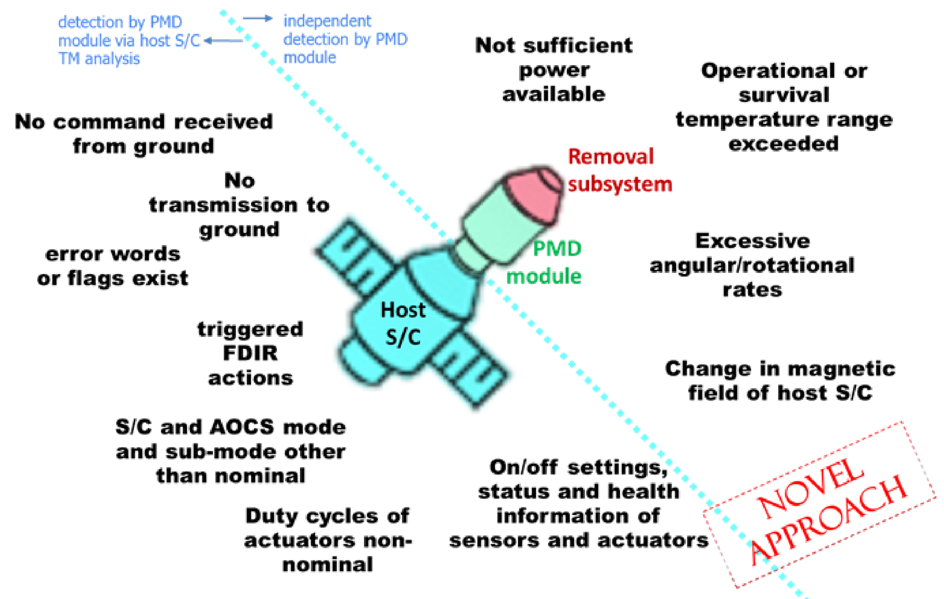

Fig.3. : *Detectable symptoms*

The passivation of the host S/C is a crucial aspect before its removal and shall prevent its accidental break-up, which would cause even more space debris. An analysis about the possible passivation measures for the host S/C from the PMD module without additional hardware and consequences with respect to the successful removal, if passivation fails, is ongoing.

3. THE REMOVAL TECHNOLOGIES

A survey of de- and re-orbit techniques and concepts was carried out, identifying approximately 40 concepts, including 12 which did not previously appear in the literature. The five most promising concepts were down-selected for further analysis. These concepts are; drag augmentation, solar sailing, electrodynamic tether, low thrust propulsion and high thrust propulsion. A further three concepts were defined by considering combinations of the down-selected concepts. The analysis was performed using a purpose built tool, which was designed to rapidly predict the re-entry of space objects. The output of the analysis provided preliminary mission parameters, systems sizing and trade-off data on each of the down-selected concepts and combination concepts. Each system had its advantages, and challenges, so no specific system could be determined as the best. Instead recommendations were made on how each system could be used to its maximum potential and which systems were more effective than others in specific situations.

Based on these results three different removal technologies to change the orbit of a S/C have been investigated and are prepared for prototyping. The focus is on scalability and standardized implementation to the module via a common interface, i.e.

- solid propulsion
- drag augmentation membrane
- electrodynamic tether

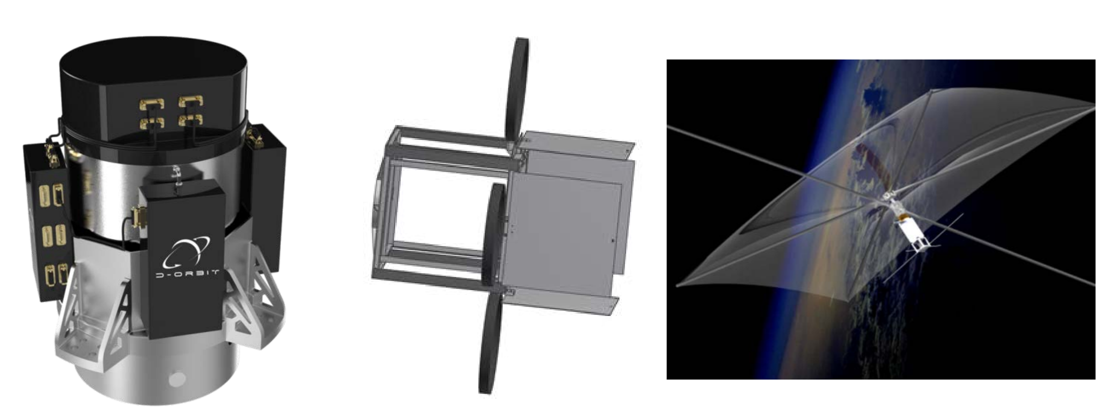

Fig.4. : *Removal subsystems for TeSeR from left to right: solid propulsion, deployable structure, electrodynamic tether*

4. ADDITIONAL INNOVATIVE CONCEPTS

SEMI-CONTROLLED RE-ENTRY CONCEPT

Uncontrolled re-entries of satellites and rocket bodies can pose an undue risk to humans on Earth due to surviving fragments. Controlled re-entries can cause additional costs for a satellite project in the order of several tens M€ (development, manufacturing, launch, and operational costs). The costs for "Design-for-Demise" are still in the order of several M€.

In contrast to the fully controlled re-entry, where the targeted impact zone has a length in the order of just a few thousands of kilometers, a semi-controlled re-entry is targeting for an impact zone with a length up to a couple orbits. Risk reduction is achieved by selecting impact orbit arcs with minimum population density.

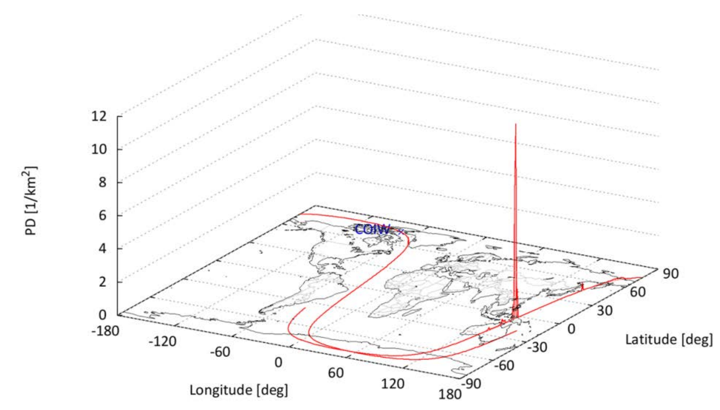

Fig.5. : *Orbit trajectory with population density*

Solutions have been found for one- or two-ton class satellites, deploying drag sails with an area of 100-200 m² in an altitude <200 km. Up to 65-99% risk reduction can be achieved. Mechanical (aerodynamic) loads on the drag sail are not an issue, but in the end, the sail fails due to aerothermal (heat) loads.

PASSIVE AOCS CONCEPTS

In the framework of passive AOCS concepts existing de-orbiting methods and devices have been studied w.r.t. their advantages and disadvantages to provide attitude control via passive means. The focus was on the potential of drag augmentation to permit passive attitude stabilization during PMD utilizing environmental effects.

One major outcome is the realization that increasing drag devices might be problematic as far as passive attitude stabilization is concerned concluding that the overall design and proper layout of the PMD module including its mounting and alignment w.r.t. the satellite to be removed by de-orbiting is crucial. The technique of numerical simulations has been used to investigate effects not covered by linear stability analysis. One example is the solar radiation pressure that depending on the considered orbit (e.g. SSO) may dominate the attitude behaviour in orbit heights above approximately 600 km altitude and lead to a change of the equilibrium state/nominal attitude originally envisaged for de-orbiting. This can be avoided if the impact of the solar radiation pressure is reduced, e.g. by the usage of transmitting drag devices which turned out to be the best solution in case the solar radiation pressure counteracts gravity gradient and aerodynamic drag as far as passive attitude stabilization is concerned.

MULTI-PURPOSE CONCEPTS

A concept for a deployable multi-purpose space debris mitigation device has been studied that could be integrated with the PMD module onto a host S/C. As a minimum, it was expected that this so-called Multi-Purpose Concept (MPC) would:

- shield the S/C against impacts from centimetre-size orbital debris and meteoroids during its mission life,
- deorbit the S/C from low Earth orbit (LEO) after the end of its mission,
- sweep small size debris (< 10 mm) from LEO, and
- detect impacts from debris and meteoroids.

Each of these functions has been evaluated and showed that the MPC has the potential to provide an effective combination of debris shielding, deorbiting and impact detection for a host S/C in LEO.

5. CONCLUSION

In the long run the PMD module could replace any PMD hardware as a new standard scalable PMD device like an external PMD subsystem. 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.

The TeSeR team has taken the first step to provide concepts for a PMD module and aims to design, manufacture and test an on-ground prototype until 2018.

6. ACKNOWLEDGEMENT

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