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Final payload test results for the RemoveDebris active debris removal mission

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ABSTRACT

Since the beginning of the space era, a significant amount of debris has progressively been generated in space. Active Debris Removal (ADR) missions have been suggested as a way of limiting and controlling future growth in orbital space debris by actively deploying vehicles to remove debris. The European Commission FP7-sponsored RemoveDebris mission, which started in 2013, draws on the expertise of some of Europe's most prominent space institutions in order to demonstrate key ADR technologies in a cost effective ambitious manner: net capture, harpoon capture, vision-based navigation, dragsail de-orbiting.

This paper provides an overview of some of the final payload test results before launch. A comprehensive test campaign is underway on both payloads and platform. The tests aim to demonstrate both functional success of the experiments and that the experiments can survive the space environment. Space environmental tests (EVT) include vibration, thermal, vacuum or thermal-vacuum (TVAC) and in some cases EMC and shock. The test flow differs for each payload and depends on the heritage of the constituent payload parts. The paper will also provide an update to the launch, expected in 2017 from the International Space Station (ISS), and test philosophy that has been influenced from the launch and prerequisite NASA safety review for the mission.

The RemoveDebris mission aims to be one of the world's first in-orbit demonstrations of key technologies for active debris removal and is a vital prerequisite to achieving the ultimate goal of a cleaner Earth orbital environment.

1. Introduction

REMOVEDEBRIS is a low cost mission performing key active debris removal (ADR) technology demonstrations including the use of a net, a harpoon, vision-based navigation and a dragsail in a realistic space operational environment, due for launch in 2017. For the purposes of the mission CubeSats are ejected then used as targets instead of real space debris, which is an important step towards a fully operational ADR mission. This paper examines the manufacture of payload hardware and both functional and environmental testing undertaken. Many of these payload concepts have never been tested in space before, and consideration is given to aspects of the test (and design) regime that differs from a conventional satellite. A brief introduction will be given to the mission, but for full details about the concept and architecture of the mission refer

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Table 1
RemoveDebris Consortium Partners.

Partner	Responsibility
SSC (Surrey Space Centre)	Project management, CubeSats, dragsail, harpoon target assembly
Airbus DS Germany	Net
Airbus DS France	Mission and systems technical lead, VBN[a]
Airbus DS UK	Harpoon
SSTL	Platform technical lead, operations
ISIS (Innovative Solutions in Space)	CubeSat deployers
CSEM	LiDAR camera
Inria	VBN algorithms
Stellenbosch University	CubeSat avionics

[a] Vision-based navigation.

to [1].

The project consortium partners with their responsibilities are given in Table 1.

1.1. Literature

One of the most active in the field of debris removal is the European Space Agency (ESA). ESA has produced a range of CleanSpace roadmaps, two of which focus on (a) space debris mitigation and (b) technologies for space debris remediation. A main part of these roadmaps is e.Deorbit, a programme spanning a host of phase studies examining removing a large ESA-owned object from space [2,3]. This initiative started with ESA's service orientated ADR (SOADR) Phase 0 study involving the analysis of a mission that could remove very heavy debris from orbit examining both the technical challenges and the business aspects of multiple ADR missions [4,5]. Progressing on, ESA has also now completed Phase A (feasibility) and Phase B1 (PDR) studies [6,7], with now several more mature designs now available. ESA's Satellite Servicing Building Blocks (SSBB) study originally examined remote maintenance of geostationary telecommunications satellites using a robotic arm [8]. The French space agency, CNES, is also widely involved in debris removal and has funded studies such as OTV which traded-off different ADR mission scenarios [9]. DLR's (German space agency) DEOS (Deutsche Orbital Servicing Mission) went as far in design as PDR level and aimed to rendezvous with a non-cooperative and tumbling spacecraft by means of a robotic manipulator system accommodated on a servicing satellite [10].

Regarding the development of capture technologies, there are several on-going efforts. Airbus DS capture designs include the robotic arm, net [11], and harpoon demonstrators for use in space [12]. The net, in particular, is considered by some studies to be the most robust method for debris removal, requiring the least knowledge about the target object [4]. The First European System for Active Debris Removal with Nets (ADR1EN) is testing net technologies on the ground with the aim of commercialising later on. A host of other capture technologies have also been proposed including: ion-beam shepherd [13], gecko adhesives and polyurethane foam [14,15]. Aviospace have been involved with some ADR studies such as the Capture and De-orbiting Technologies (CADET) study which is examining attitude estimation and non-cooperative approach using a visual and infra-red system [16] and the Heavy Active Debris Removal (HADR) study that examined trade-offs for different ADR technologies, especially including flexible link capture systems [17].

Although recently there have been advances in relative space navigation, the complex application of fully uncooperative rendezvous for debris removal has not yet been attempted. Vision-based relative navigation (VBN) systems, which would be necessary for future debris removal missions are currently being developed and will be demonstrated on RemoveDebris [18–20]. Other recent research specifically related to VBN for debris removal includes: TU Dresden [21], Thales [22], Jena-Optronik [23].

A range of de-orbitation technologies have been proposed previously but few have had in-flight testing. Research includes: dragsails (InflateSail, DeOrbitSail) [24], TeSeR (which proposes an independent modular deorbitation module that attaches to the satellite before launch) [25], BETS - propellantless deorbiting of space debris by bare electrodynamic tethers (which proposes a tether-based removal system), solid rocket deorbitation (proposed D-ORBIT D-SAT mission) [26].

Regarding rendezvous in space, the Autonomous Transfer Vehicle (ATV) was one of the first times a spacecraft initiated and commenced a docking manoeuvre in space in a fully autonomous mode [27]. The Engineering Test Satellite VII 'KIKU-7' (ETS-VII) by JAXA in 1997 was one of the first missions to demonstrate robotic rendezvous using chaser and target satellites [28]. The AoLong-1 (ADRV) 'Roaming Dragon' satellite was also recently launched by CNSA (China National Space Administration) in 2016 in order to test target capture with a robotic arm; results are presently not available. Most recently JAXA's HTV-6 vehicle, which launched in early 2017, unsuccessfully attempted to deploy an electrodynamic tether under the Kounotori Integrated Tether Experiment (KITE) [29].

Upcoming missions to tackle debris removal include CleanSpace One by EPFL, which aims to use microsatellites with a grabber to demonstrate capture [30,31]. The mission is still under design and launch is not foreseen for a few years. As mentioned previously, ESA's e.Deorbit will likely result in a large scale mission and is currently proposed for 2023. Of interest is AstroScale, a company based in Singapore, aiming to launch

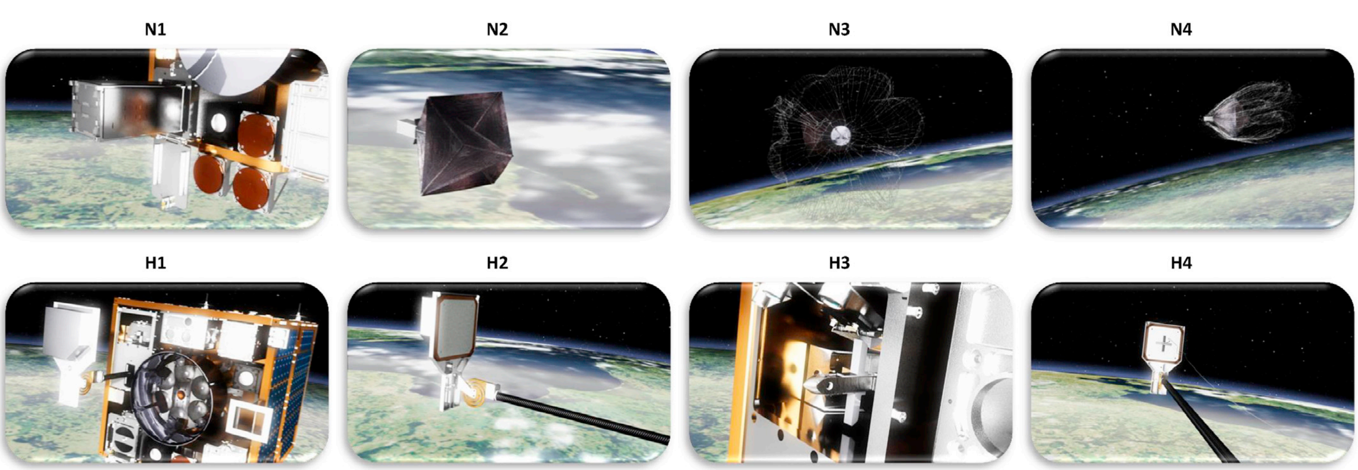

Fig. 1. Experimental Sequence. This figure shows the experimental sequences for the net (N1 to N4) and harpoon (H1 to H4): (N1) DS-1 CubeSat ejection, (N2) inflatable structure inflation, (N3) net firing, (N4) net capture, (H1) harpoon target plate extended, (H2) target plate reaches end, (H3) harpoon firing, (H4) harpoon capture.

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