REMOVEDEBRIS MISSION, IN ORBIT OPERATIONS

G S. Aglietti, B Taylor, S Fellowes
Surrey Space Centre, University of Surrey
Guildford, GU2 7XH, United Kingdom,+44(0)1483 683417 .aglietti@surrey.ac.uk

S. Ainley, D Tye, C. Cox, A, Zarkesh, A. Mafficini, N. Vinkoff, K. Bashford
Surrey Satellite Technology Ltd.
20 Stephenson Rd, Guildford GU2 7YE; United Kingdom, +44 (0)1483 803803. S.Ainley@sstl.co.uk

T. Salmon
Airbus Safran Launchers, Rue du Général Niox, 33165 Saint-Médard-en-Jalles, France,
+33 5 56 57 30 00 thierry.salmon@airbusafran-launchers.com

I Retat,
Airbus Defense & Space, Airbus Allee 1, 28361 Bremen,
+49 421 539 0 ingo.retat@airbus.com

C. Burgess, A. Hall,
Airbus Defense and Space Gunnels Wood Rd, Stevenage SG1 2AS, United Kingdom
+44 1438 778 151 christopher.burgess@airbus.com

T. Chabot, K Kanani, A.Pisseloup,
Airbus, 31 Rue des Cosmonautes, 31400 Toulouse, France
+33 5 62 19 62 19 aurelien.pisseloup@airbus.com

C. Bernal
ISIS Space, Motorenweg 23, 2623 CR Delft, Netherlands,
+31 15 256 9018, c.bernal@isispace.nl

F. Chaumette,
Inria, Domaine de Voluceau, Rocquencourt - BP 105, 78153 Le Chesnay Cedex
+33 (0)1 39 63 55 11, francois.chaumette@inria.fr

A.Pollini
Rue Jaquet-Droz 1, 2002 Neuchâtel, Switzerland
+41 32 720 5111, alexandre.pollini@csem.ch

W. H. Steyn
Department E&E Engineering, Stellenbosch University, Stellenbosch, 7600, South Africa
+27 21 808 4926 whsteyn@sun.ac.za

ABSTRACT

The RemoveDebris mission has been the first Active Debris Removal (ADR) mission to give in orbit demonstrations of cost effective technologies that can be used to observe, capture and dispose of space debris.

The craft was launched to the ISS on the 2nd of April 2018, on board a Dragon capsule. From here the satellite was deployed via the NanoRacks Kaber system into an orbit at 405km altitude and has performed key technology demonstrations including the use of a net, a harpoon, vision-based navigation (VBN) and a dragsail in a realistic space operational environment.

Two CubeSats have been released by the main platform and used as targets for the net demonstration and for the VBN, whereas the harpoon demonstration has used a target mounted at the end of a boom deployed from the platform. These have been the first ever in-orbit successful demonstrations of technologies for large space debris capture. The dragsail demonstration presented some anomalies, however the lessons learned have already been implemented in new successful dragsails already deployed in space missions.

This paper briefly outlines the development of the mission, discussing some of its challenges, and focusses on the various in orbit experiments, describing the operations and overall outcomes.

INTRODUCTION

This article describes the RemoveDEBRIS mission, and in particular it focuses on its execution, from the launch of the craft to the ISS - from where the satellite was then deployed in orbit on the 20th of June 2018 - to the end of the in-orbit mission operations in March 2019. Lift off was on the 2nd of April 2018, on board a Dragon capsule on a Space X Falcon 9 Rocket used for the periodic resupply of the ISS [1], and the capsule arrived at the ISS 2 days later.

This mission has been developed by a consortium of 10 institutions (see Table 1), supported by a research grant of the European Commission. RemoveDEBRIS has been the first mission to achieve a successful in-orbit demonstration of technologies for the active removal of space debris [2]. Technologies that are particularly suitable for large debris such as satellites that are no longer working, and which are currently tracked [3] in “busy” orbits, posing a threat for new satellites.

The consortium came together in 2012-13, and the project started in 2013. The evolution of the design is recorded in various journal articles [5, 6] and international conference proceedings [6, 7, 8, 9].

Various technologies have been conceived to capture space debris, as reported in [10, 11] and the RemoveDEBRIS project aimed at progressing some of the most cost effective technologies, as cost will be a significant factor in determining the future of Active Debris Removal (ADR).

In essence the mission consisted of a main mini satellite platform of approximately 100kg mass that has released two 2U cubesats which acted as space debris. As the two cubesats were released at low speed it was not necessary for the platform to have its own propulsion system in order to “chase” its targets, but these slowly drifted away allowing the testing of the technologies when the targets (i.e. the cubesats) were at an appropriate distance from the mothercraft.

The first cubesat, DSAT#1, was released on the 16th of September 2018 and, after a slow speed push-off from the mothercraft, whilst drifting away, it deployed inflatable structures in order to increase its size becoming more representative of real larger space debris. The cubesat has then been captured by a net launched by the mothercraft when this was approximately 10 meters away, with the whole operation recorded by the supervision cameras mounted on the mothercraft.

The second cubesat, DSAT#2, was released on the 28th of October 2018, with a low speed ejection from the satellite platform and while drifting away it was observed using the Vision Based Navigation (VBN) system to test its hardware and algorithm capability. DSAT#2 also relayed its own measured position and attitude data back to the mothercraft for validation purposes.

Next the harpoon experiment was performed, where a small Honeycomb panel of construction analogous to that used in standard older satellites structures was deployed using a boom that positioned it at a 1.5 meter distance from the platform. This panel/target was then hit by the harpoon fired from the satellite platform.

The last experiment consisted in the deployment of a dragsail, as during any mission de-orbiting of the satellite would be the last phase of the in-orbit operations. This last experiment showed some anomalies that will be discussed in the paper.

The mission design has tried to ensure that the payloads are as representative as possible for future missions and have scalability potential to larger classes. In certain cases, the mission had to give priority to practicality, satisfying regulatory (licensing) requirements or safety requirements. For instance, sizing of the platform and payload targets was in part selected to ensure the artificial debris would re-enter in a timely fashion whether or not the mission was successful. Similarly a low altitude orbit was selected to ensure prompt disposal of the mission. This led to a launch from the ISS, as its orbit, at approximately 405km altitude guaranteed a rapid re-entry of all the objects.

One of the aims of the mission was to demonstrate that the debris removal demonstration can be performed at “low cost”, which posed significant limitations on the budget. The need to contain cost pointed again to a launch from the ISS as a more cost effective launch solution in comparison to available piggy back launches. In turn, the launch from the ISS imposed some limitations on the size and mass of the craft, together with some restrictions and further design & test requirements in order to guarantee, at all times, the safety of the ISS and its crew.

MISSION DEVELOPMENT

The various elements of this mission were developed by the partners of the consortium as shown in Table 1. The payloads were designed, built and initially tested at the partners’ facilities, and then delivered to SSTL for the final AIT of the platform.

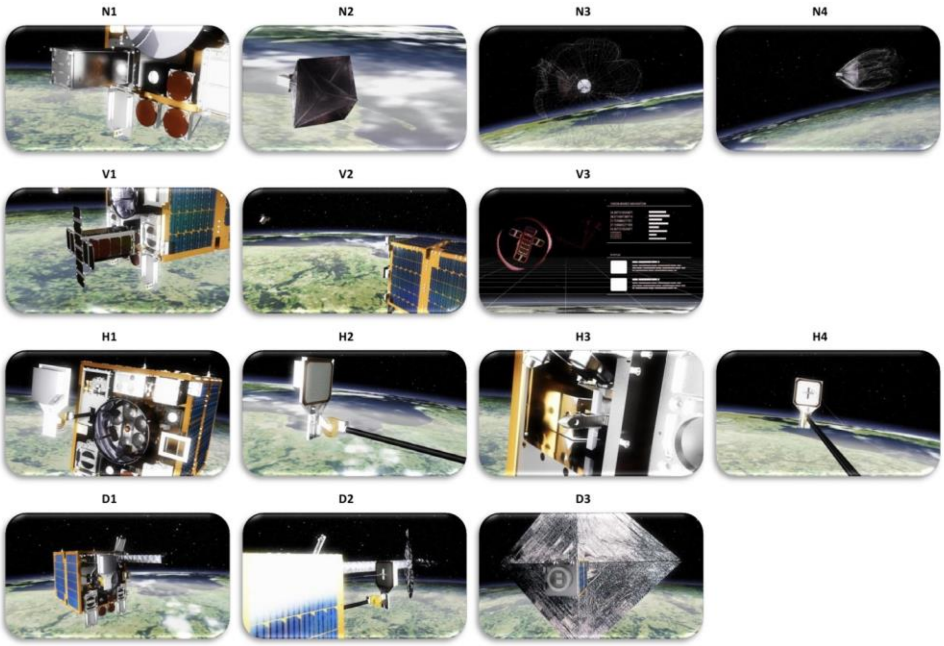

Figure 1: N1 to N4: net experiment, V1 to V3: vision-based navigation experiment, H1 to H4: harpoon experiment, D1 to D3: dragsail experiment.

The overall schedule of the project is shown in Table 2 and the plans for the in-orbit demonstrations are pictorially summarized in Figure 1.

Concerning the launch, as the craft was stored as cargo in the Dragon capsule, this posed some challenges in terms of determining exactly the vibration environment that the craft would have experienced, and derive appropriate levels for testing. In addition the load path was completely different from a standard launch where the satellite is constrained by its release mechanism

Table 1: RemoveDebris Overall Mission Chronology

Partner	Country	Business	Roles in the project
SSC (coordinator)	UK	University (Research)	Project management CubeSats, Dragsail, Harpoon Target Assy
SSTL	UK	Satellite Prime	Platform provider, Satellite operations
Airbus D&S	D	Prime for space transportation and satellites	Payloads: Net
Airbus D&S	F		Mission & System Eng., P/oads: Vision-Based Nav. & VBN algorithms
Airbus D&S	UK		Payloads: Harpoon
Ariane Group	F	Prime for space transportation and satellites	Mission & System Engineering
ISIS	NL	SME, nanosatellites	Payloads: CubeSat deployers
CSEM	CH	Research Institution	Payloads: LiDAR camera
INRIA	F	Research Institution	Payloads: VBN algorithms
STE	South Africa	University (Research)	Payloads: CubeSat avionics

Some other challenges for the development of the hardware related to ensuring compliance with the NASA safety requirements that had to be demonstrated during the three levels of the NASA safety reviews.

Table 2: RemoveDebris Overall Mission Chronology

Event	Date
Start of RemoveDEBRIS project (Kick off)	October 2013
PDR (Preliminary Design Review)	December 2014
Platform CDR (Critical Design Review)	March 2017
Satellite FRR (Flight Readiness Review) & AR (Acceptance Review)	December 2017
Transfer to US	December 2017
Launch	2nd April 2018
Release from ISS	20th June 2018
End of LEOP & commissioning	August 2018
Net Experiment	16th September 2018
Vision Based Navigation Experiment	28th October 2018
Harpoon Experiment	8th February 2019
DragSail Experiment	4th March 2019
End of Life (planned)	2020-2021

Items such as the Cold Gas Generators and the battery presented some issues, the first related to the nature of the chemicals in the device, the latter due to its size and energy. The RemoveDEBRIS platform used an 80 cell battery supplied by ABSL consisting of 1400mAh SONY US18650S in a 8s10p configuration. Although ABSL are market leaders in the manufacture and qualification of spacecraft batteries no test results were available for the exact 8s10p configuration being flown. Therefore a test battery was produced by the SSC to demonstrate battery safety under thermal runaway conditions.

Those mentioned above are just representative examples, and the lesson learned from the process is that early engagement with the NASA safety board enables to integrate the required features directly in the design, rather than forcing modifications afterwards.

LAUNCH AND DEPLOYMENT OPERATIONS

At the end of AIT activities in the SSTL cleanroom in Guildford UK, the satellite was shipped to Cape Canaveral for launch

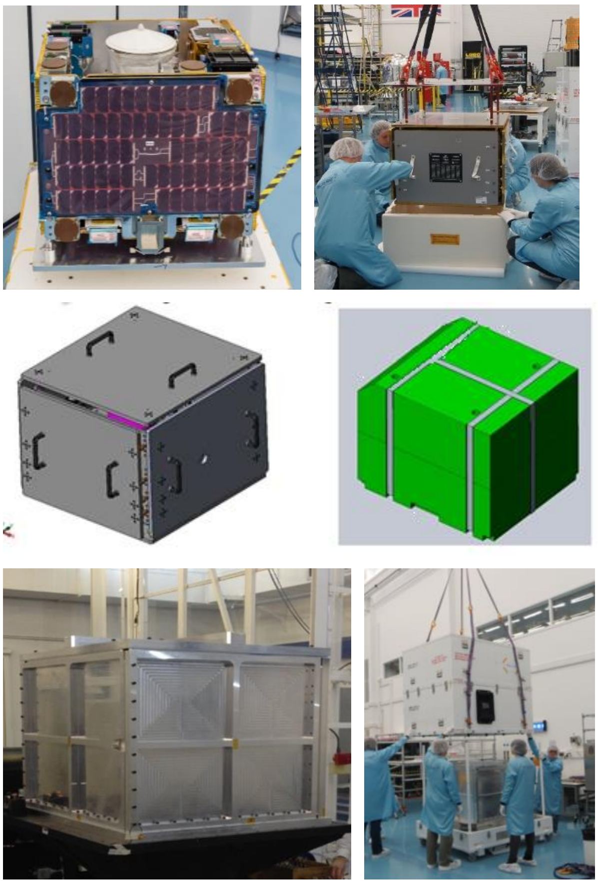

Figure 2. Top Left: RemoveDEBRIS, Top Right: RemDEB with protective panels going in the foam clam-shell, Mid Left CAD model of RemDEB with protective panels, Mid Right: RemDEB in the clam shell, Bottom Left: Assembly in Aluminum casing, Bottom Right: Assembly in Aluminum casing going in transportation case.

For protection purposes during transportation, aluminum honeycomb panels were mounted on the sides of the satellite, and the assembly was then incased in a foam shell (see Figure 2). The foam shell was then encased in an aluminum box, as used for the vibration testing, and this was finally enclosed in the transportation case.

Once at the launch site, the external casing was removed, leaving the craft with its protective panels in the foam shells. In this configuration the craft was put in the cargo transfer bag (CTB) and finally in the Dragon capsule.

Launch was nominal and when the craft arrived on the ISS the CTB, foam casing and protective panels were removed and the craft was mounted on the sliding table in the Japanese module airlock (see Figure 3). Once on the other side of the airlock the craft was handled by the ISS robotic arm and release as shown in Figure 3).

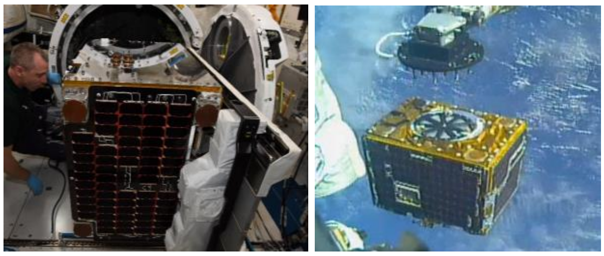

Figure 3. Left: RemoveDEBRIS mounted on the sliding table of the airlock, Right: RemoveDEBRIS at the moment of the release from the robotic arm of the ISS

Commissioning and Early Operations Phase (LEOP)

Contact with the craft was made during the first pass after power up, over the SSTL groundstation in Guildford UK. Note that due to ISS safety requirements the craft had to be kept switched off for at least 30 minutes from its release from the ISS.

The telemetry that was downloaded showed that the spacecraft was performing nominally, e.g. Battery was fully charged, and temperatures as expected.

Commissioning progressed with switch on of the spacecraft On Board Computer the progressed with de-tumbling from the slow initial angular rate to a controlled attitude state. Attitude and Orbital Control System commissioning progressed until the platform was in a coarse Nadir pointing mode.

The next phase involved some platform checks, to verify health and functioning of the key modules not already checked. Prime and redundant RF receivers, low rate transmitters and low level command links were tested. The spacecraft then performed a series of AOCS maneuvers to verify performance against that required for executing payload experiments.

The final phase was the payload calibration and characterisation. The Supervision cameras and VBN camera were tested over a range of exposures and frame rates which were planned for use on the experimental demonstrations and related parameters were adjusted.

IN ORBIT DEMONSTRATIONS

Net capture demonstration

The first demonstration to take place was the Net capture. This demonstration required the release of the Cubesat DSAT#1, at low speed (V=5cm/s), and this to inflate its deployable structures in order to become more representative of the size of a large space debris. DSAT#1 in its stowed and deployed configuration is shown in Figure 4.

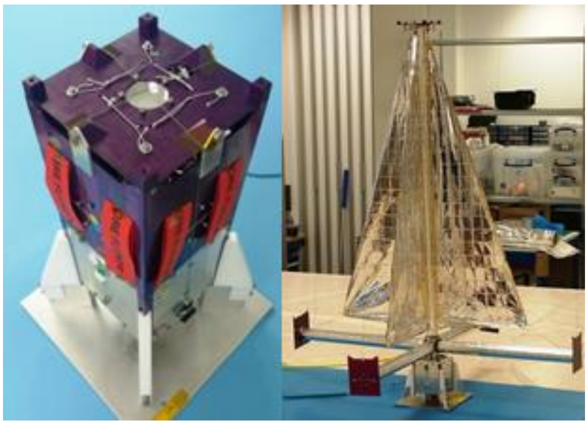

Figure 4. Left: DSAT#1 in its stowed configuration; Right: DSAT#1 with its inflatable structures fully deployed

Figure 5: DSAT#1 with lateral inflatable booms deployed

On the 16th of September, DSAT#1 was deployed by the ISIS deployer as planned, and triggered by a timer its deployables were actuated. Measurements of the velocity with which the cubesat drifted away from the mothercarft showed a speed of approximately 7.5m/s; slightly higher than planned but still appropriate for the experiment. Two of the four lateral deployable booms deployed as planned (Figure 5) and so did the longitudinal deployable boom. The latter is visible in the video-footage of the Net capture experiment, as recorded by the two surveillance cameras mounted on the mothercraft to video the experiment.

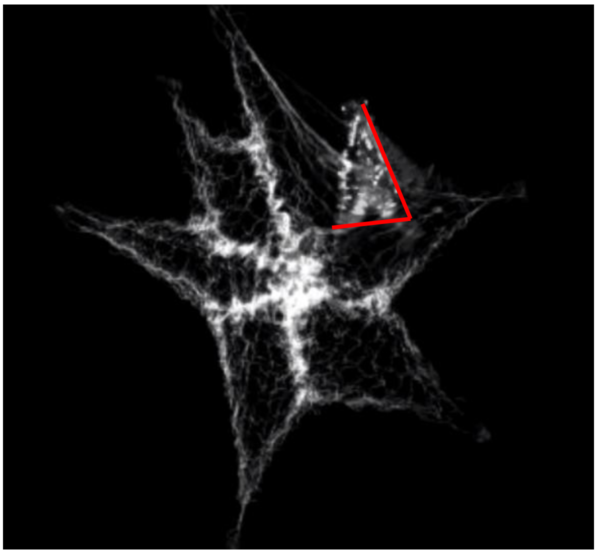

Figure 6: Moment of the Net capture of DSAT#1, one of the satellite sails is shown, between the lateral and longitudinal booms

Figure 6 shows the moment of the capture, at the edge of the Net, from where it is possible to see one of the 4 sails of DSAT#1, between one of the lateral booms and the longitudinal boom.

VBN Demonstration

The purpose of the VBN demonstration was to assess the state-of-the-art of Image Processing (IP) and navigation algorithms based on actual flight data, acquired through two sensors: a standard high quality camera and a flash imaging LiDAR system.

The device is shown in Figure 7, together with the cubesat DSAT#2 that was released by the mothercraft in order to be observed by the two cameras to then be able to reconstruct the dynamics of the object from the "pictures" acquired via the cameras.

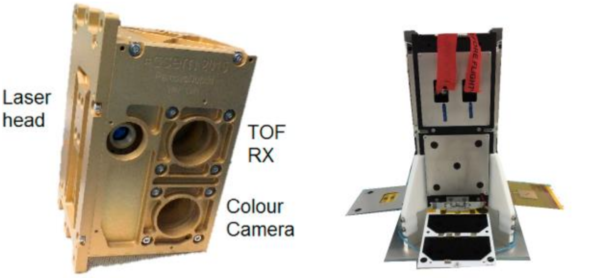

Figure 7. Left: Vision Based Navigation payload, Right: DS-2 target in deployed state

Once released by the ISIPOD#2, DSAT#2 drifted away from the mothercraft at a velocity of 2 cm/s.

One of the challenges is to recognise the target independently from the background (see Figure 8), and this experiment provided a wealth of real data to assess the performances and robustness of the VBN algorithms.

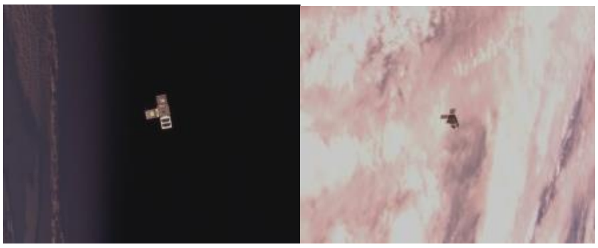

Figure 8: DSAT#2 with different backgrounds.

Lidar imagery directly delivers information about the target distance, and this data was compared with the measurements obtained by the GPS on board the CubeSat, which were relayed to the mothercraft via an inter satellite link. This data and the GPS information for the mothercraft allowed calculation of the distance between the objects, and use of this as a reference to establish the quality of the LiDAR measurements, which was found to be in line with the expectations.

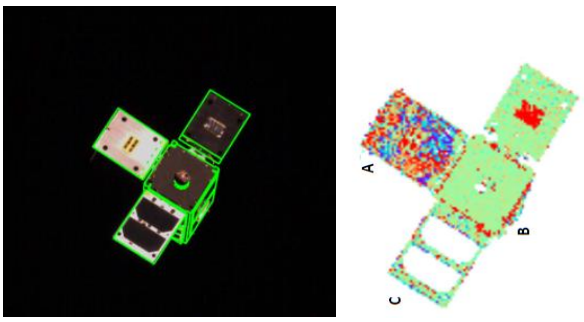

Figure 9: Left: View of DSAT#2 with shape contours, Right: image from LiDAR camera

Harpoon Demonstration

The harpoon demonstration was carried out firing the Harpoon on a target representative of structural panels on old, large satellites, which are potential targets for this technology. The target was deployed at the end of a 1.5m long boom as shown in Figure 10, and more details can be found in [12, 13].

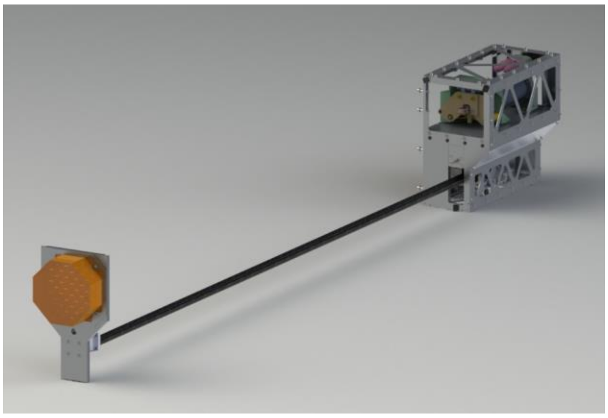

Figure 10: Harpoon Target Assembly in its deployed configuration.

As the target was deployed a significant oscillation developed on the structure with the target oscillating around its nominal position as shown in Figure 11.

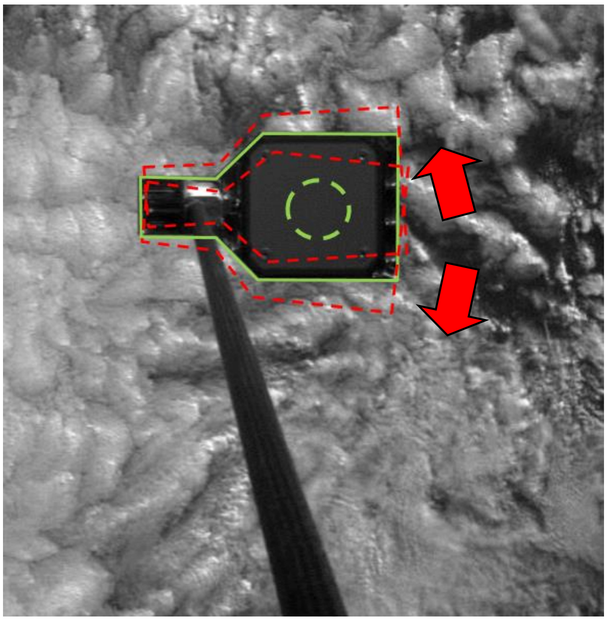

Figure 11: Target deployed at the end of the boom, in green the nominal position and in red the positions at the extreme of the scallions whose direction is indicated by thee red arrows

The oscillations were excited by the inputs produced by on board equipment (AOCS), and minimizing the action of the AOCS it was possible to stabilize the boom in order to be able to carry out the experiment with sufficient reliability.

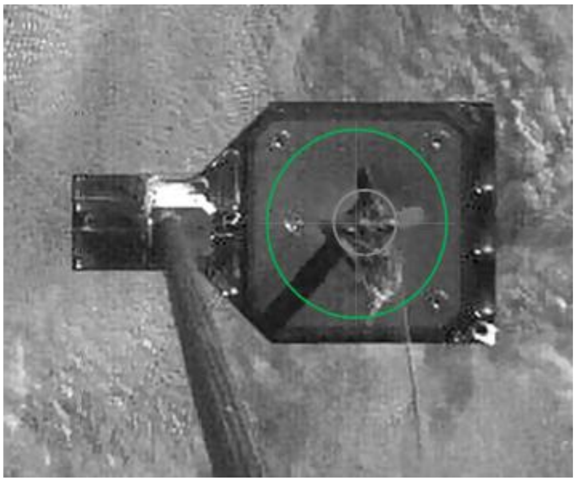

Figure 12: Harpoon imbedded in the target

On the 8th of February 2019 the harpoon was fired at the target. The harpoon travelled at a speed of 19m/s and hit the target in the centre as shown in Figure 12. The target was snapped off of the end of the boom (see Figure 13), due to the mechanical shock, it was retained by the harpoon which was tethered to the mothercraft.

The floating target eventually wrapped itself around the deployable boom as shown in Figure 13.

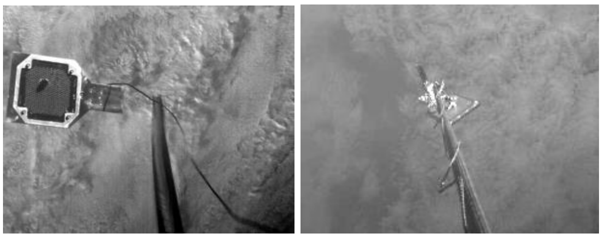

Figure 13: Left Target captured by the harpoon, floating in space tethered to the mothercraft. Right Target and tether line wrapper around the boom.

Dragsail Demonstration

The last experiment to be performed was the dragsail, as in any mission the deployment of this device to de-orbit the craft would be the last phase of the in-orbit operations.

This payload that was delivered for integration in the mothercraft is shown in Figure 14 and when operated, the inflatable mast extends 1m out of the enclosure and CFRP booms deploy radially outwards to unfold the sail. Once deployed the dragsail is very similar to that used for the cubseat InflateSAIL that is shown in Figure 15 (see refs. [14, 15 16]).

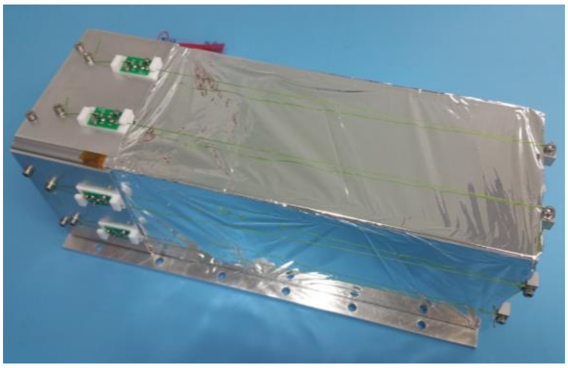

Figure 14: RemoveDEBRIS dragsail payload

Figure 15: InflateSAIL with inflatable mast and sail deployed

As this payload was mounted on the back of the mothercraft in order not to interfere with the other payloads (Net, VBN and HTA) it was not possible to video this experiment, as all the supervision cameras were on the other side of the craft, to monitor the other three demonstrations. For the Dragsail, successful demonstration would have been indicated by a significant increase in the decay rate of the mothercraft, by some changes in the outputs pattern of the solar panels (as these at times would be obscured by the sails), and by an increase in the brightness of the satellite from ground observations.

The command to deploy the sail was given on the 4th of March 2019. From the ground, a small increase in the brightness of the object (the RemoveDEBRIS mothercraft) was detected, however, there was no significant change in the output of the solar panels, and the decay of the altitude of the object has not accelerated as expected (see Figure 16). These factors point to a possible partial deployment of the sail.

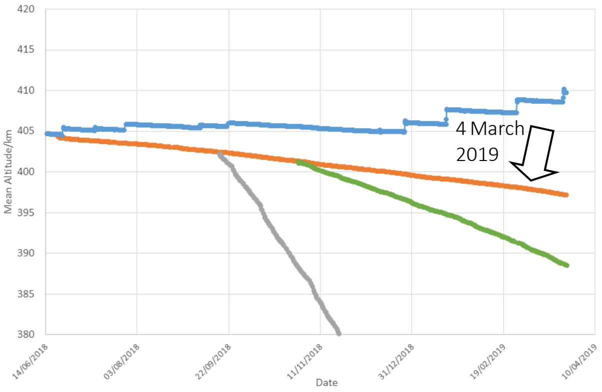

Figure 16: RemoveDEBRIS altitude of various objects. Blue - ISS, Orange - RemoveDEBRIS mothercraft, Grey – DSAT#1, Green DAT#2

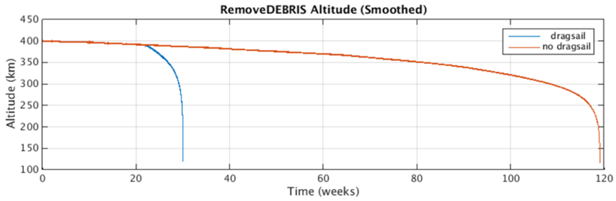

Figure 17: Prediction of the decrees in orbit altitude for RemoveDEBRIS satellite, with and without deployed dragsail.

However based on the lesson learned from the development and MAIT of the RemoveDEBRIS' dragsail, improvements were made on the dragsail of the cubesat InflateSAIL and on two further dragsails (see Figure 18) that were used for the Spaceflight Industries' SSO-A mission. All three sails have deployed successfully in orbit with InflateSAIL having already re-entered and therefore the development of the RemoveDEBRIS dragsail had its usefulness as it paved the way for the development of these commercial devices.

Figure 18: Dragsail for the Space Flight Industries' SSO-A mission

One final comment is that even without the dragsail fully deployed, the two cubesats and the craft are deorbiting as planned. With reference to Figure 16, the first of the cubesatas has already been de-orbited (2nd of March 2019), the second should be de-orbited in the next few months, and the mothercraft during its first year in orbit has already lowered its altitude by more than 10km, and therefore is due to completely de-orbit, burning in the atmosphere in the next couple of years. Considering that the platform was released in orbit at an altitude slightly higher than planned (405km, versus the 400km used for the simulations in Figure 17), the decay of the craft is consistent with what was initially predicted, reported in Figure 17, and indeed well within the current guidelines.

CONCLUSION

This article has briefly described the RemoveDEBRIS mission, with emphasis on the in-orbit operations.

The demonstrations of the Net and Harpoon target technologies have confirmed that these are indeed viable technologies for the removal of large space debris. The hardware will need scaling up, due to the larger size of potential real targets, but the basic technology is sound and the in orbit demonstrations have provided a valuable experience to de-risk future developments.

The VBN demonstration has also been successful, collecting a great amount of data and proving the performance of hardware and software in the real environment.

The dragsail experiment manifested some anomalies, however, this has paved the way for successful commercial exploitation in the new devices that have been produced by SSC.

The mission has also been successful in getting a variety of institutions working together to tackle a global issue, from large to small companies, universities and research centers, sharing best practice and improving their competitiveness.

Acknowledgments

This research is supported by the European Commission FP7-SPACE-2013-1 (project 607099) 'RemoveDEBRIS - A Low Cost Active Debris Removal Demonstration Mission', a consortium partnership project consisting of: Surrey Space Centre (University of Surrey), SSTL, Airbus DS (formerly Astrium) GmbH, Airbus SAS, Airbus Ltd, Airbus Safran Launchers, Innovative Solutions in Space (ISIS), CSEM, Inria, Stellenbosch University.

The authors would also like to acknowledge the help and support of launching agent NanoRacks as this has been crucial to deliver successfully this mission.

References

1. SpaceX Commercial Resupply Mission CRS-14 https://www.spacex.com/news/2018/04/02/dragon-resupply-mission-crs-14 accessed 10/06/2019
2. H. Stokes, *Space Debris - Encyclopedia of Aerospace Engineering - Klinkrad - Wiley Online Library*. John Wiley & Sons, Ltd, 2011.
3. A. Petit, E. Marchand, K. Kanani, Tracking complex targets for space rendezvous and debris removal applications, in: IEEE/RSJ Conference on Intelligent Robots and Systems, IROS'12, Vilamoura, Portugal, 2012.
4. Forshaw, J. L., Aglietti, G. S., Salmon, T., Retat, I., Roe, M., Burgess, C., Chabot, T., Pisseloup, A., Phipps, A., Bernal, C., Chaumette, F., Pollini, A. and Steyn, W. H., "Final Payload Test Results for the RemoveDebris Active Debris Removal Mission", *Acta Astronautica*, 2017 doi:10.1016/j.actaastro.2017.06.003
5. J.L. Forshaw, G.S. Aglietti, N. Navarathinam, H. Kadhem, T. Salmon, A. Pisseloup, E. Joffre, T. Chabot, I. Retat, R. Axthelm, S. Barraclough, A. Ratcliffe, C. Bernal, F. Chaumette, A. Pollini, W.H. Steyn, RemoveDEBRIS: an in-orbit active debris removal demonstration mission, Acta Astronautica 127 (2016) 448–463, http://dx.doi.org/10.1016/j.actaastro.2016.06.018.
6. B Taylor, G Aglietti et al. "The RemoveDebris Mission, From Concept To Orbit", in the proceedings of the SmallSat Conference, Utah, SSC18-I-03 USA, 4-9 August 2018
7. Forshaw, J. L., Aglietti, G. S., Salmon, T., Retat, I., Hall, A., Chabot, T., Pisseloup, A., Tye, D., Bernal, C., Chaumette, F., Pollini, A. and Steyn, W. H., "The RemoveDebris ADR Mission: Launch from the ISS, Operations and Experimental Timelines", *68th International Astronautical Congress*, Adelaide, Australia 2017.
8. B. Taylor, Guglielmo S. Aglietti, S. Fellowes, T. Salmon, A. Hall, T. Chabot, A. Pisseloup, S. Ainley, D. Tye, I. Retat, C. Bernal, F. Chaumette, A. Pollini, W. Steyn, "RemoveDebris Preliminary Mission Results" International Astronautical Congress, IAC-18-A6.1.5, Bremen, Germany 1-5 Oct 2018.
9. Forshaw, J. L., Massimiani, C., Richter, M., Viquerat, A., Simons, E., Duke, R. and Aglietti, G. S., "Surrey Space Centre: A Survey of Debris Removal Research Activities", *66th International Astronautical Congress*, Jerusalem, Israel. 2015
10. Minghe Shan, Jian Guo, Eberhard Gill, "Review and comparison of active space debris capturing and removal methods" Progress in Aerospace Sciences, Volume 80, January 2016, Pages 18-32
11. C. Rpiyant Mark, Surekha Kamath, "Review of Active Space Debris Removal Methods" Space Policy, 47 pp194- 206, 2019
12. G S. Aglietti, J. Forshaw, A. Viquerat, B. Taylor, "An overview of the mechanisms and deployables on the removedebris ADR mission", *European conference on Spacecraft Structures Materials and Mechanical Testing*, 28 May 1st June 2018, Noordwijk, NL 2018
13. Fernandez JM, Visagie L, Schenk M, Stohlman OR, Aglietti GS, Lappas VJ, Erb S. "Design and development of a gossamer sail system for deorbiting in low earth orbit" Acta Astronautica Volume 103, October–November 2014, Pages 204–225 DOI: 10.1016/j.actaastro.2014.06.018
14. CIU Underwood, A. Denis, A. Viquerat, B. Taylor, B. Sanders, B. Stewart, C. Massimiani, C. Bridges, D. Masutti, G. Aglietti, M. Schenk, R. Duke, S. Fellowes, "InflateSail De-Orbit Flight Demonstration Results and Follow-On Drag-Sail Applications" Acta Astronautica – in press.
15. Underwood, C., Viquerat, A., Schenk, M., Fellowes, S., Taylor, B., Massimiani, C., Duke, R., Stewart, B., Bridges, C., Masutti, D., Denis, A., "The InflateSail CubeSat Mission – The First European Demonstration of Drag-Sail De-Orbiting", *4th IAA Conference on University Satellite Missions and CubeSat Workshop*, Rome, Italy, 2017
16. Secheli, G., Viquerat, A. and Aglietti, G. S, "Mechanical Development of a Novel Inflatable and Rigidizable Structure", *3rd AIAA Spacecraft Structures Conference*, San Diego, California, US 2016.