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# REMOVEDEBRIS MISSION, FROM CONCEPT TO ORBIT

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

S. Ainley
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.T. Chabot, K Kanan
Airbus Toulouse thomas.t.chabot@airbus.com

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 will be the first European Active Debris Removal (ADR) missions to give an in orbit demonstration of the viability of a series of cost effective technologies that can be used to observe, capture and destroy space debris.

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 (VBN) and a dragsail in a realistic space operational environment. For the purposes of the mission two CubeSats will be ejected and used as targets for experiments instead of real space debris, which is an important step towards a fully operational ADR mission.

The craft has launched to the ISS on the 2nd of April 2018, on board a Dragon capsule (SpaceX CRS-14 ISS re-supply mission). From here the satellite is to be deployed via the NanoRacks Kaber system into an orbit of around 400 km.

This paper examines the design of the mission from initial concepts through to manufacture, AIT, testing and up to launch, and apart from a general consideration of the mission, will focus on the elements of design & testing that differ from a conventional mission.

## INTRODUCTION

The mission concept consists of a main mini satellite platform of approximately 100kg mass that once in orbit will release two 2U cubesats which will act as space debris simulators. Four key technologies, to be used at different stages of a typical Active Debris Removal (ADR) mission will be tested: Vision Based Navigation (VBN) as a tool to observe and quantify the relative dynamics between an uncooperative debris and the platform preparing for its retrieval; two technologies for debris capture, namely a net and a harpoon; and finally a de-orbit sail, to increase the satellite platform drag, thus reducing its speed and orbit altitude until it burns up in the Earth's atmosphere.

One of the cubesats, after low speed ejection from the satellite platform will be observed using the VBN to prove its hardware and algorithm, whilst the CubeSat also relays attitude data to the satellite platform for validation. The second cubesat, after ejection, will inflate a structure to increase its size to make it comparable to that of larger debris becoming a more size-representative target for the net capture experiment i.e. a net will be launched by the platform to envelope and capture the cubesat. A small panel of material analogous to that used in standard satellites construction will then be deployed using a boom that will position this panel at a 1.5 meter distance from the platform. This panel will be the target for the harpoon experiment (i.e. a tethered harpoon is going to be fired by the satellite platform to hit this panel). The last experiment to be performed will be the drag sail. During a real mission this would be the last phase, when the platform and the debris that it has captured are deorbited together, destroying through burn-up.

## MISSION MOTIVATION AND CONCEPT

Figure 1, from the NASA Orbital Debris Program Office shows the number of space objects greater than ~10cm diameter tracked and catalogued by the US Space Surveillance Network up to 2010 [1, 2]. The categories of object are broken down into spacecraft (operational and non-operational), orbiting rocket bodies, mission-related debris (e.g. payload shrouds), and fragmentation debris. It can be seen that fragmentation debris is by far the largest contributor to the total number of objects on the graph. Such debris is created when objects collide. For example, in 2009, two artificial satellites: Kosmos-2251 and Iridium-33 collided accidentally, producing a large quantity of debris, which can be seen as the last step change in the fragmentation debris shown on the graph[1]. The two previous step changes were due to deliberate orbital fragmentation events – those of the Chinese satellite FengYun-1C (2007) and the American satellite USA-193 (2008).

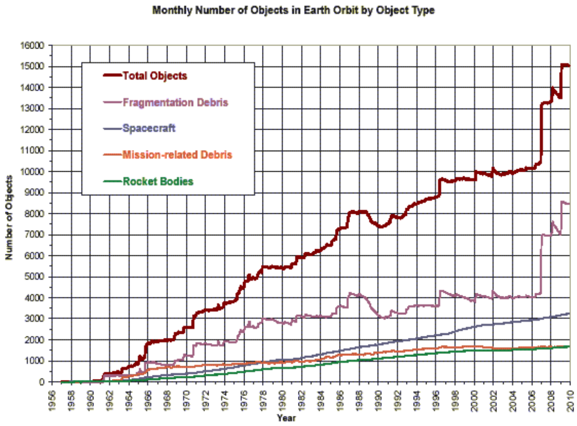

**Figure 1. Growth of the Orbital Debris Problem – NASA Orbital Debris Program Office**

The growth of Space debris is a clear challenge for the 21st century which can be tackled both by Post Mission Disposal (PMD), i.e.: self-disposal by satellites at end of operational lifetime and Active Debris Removal (ADR). The RemoveDebris mission was conceived to perform an initial demonstration of key ADR technologies to provide experience and characterize performance prior to an operational mission. As such, the mission focusses on the payload operations and does not include tracking and orbit rendezvous of pre-existing debris, a significant, but distinct challenge.

Figure 2 shows the sequencing of the four experiments in the mission. The net sequence is: (N1) DS-1 CubeSat ejection, (N2) inflatable structure inflation, (N3) net firing, (N4) net capture. The VBN sequence is: (V1) DS-2 CubeSat ejection, (V2) DS-2 drifts away, (V3) VBN system collects data. The harpoon sequence is: (H1) harpoon target plate extended, (H2) target plate reaches end, (H3) harpoon firing, (H4) harpoon capture. The dragsail sequence is: (D1) inflatable mast deploys, (D2) sail starts deployment, (D3) sail finishes deployment.

The mission design [11] has tried to ensure the payloads are 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 payload targets was 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.

Table 1 below provides a summary of the sequence of events in the mission operations from launch through to end of life disposal.

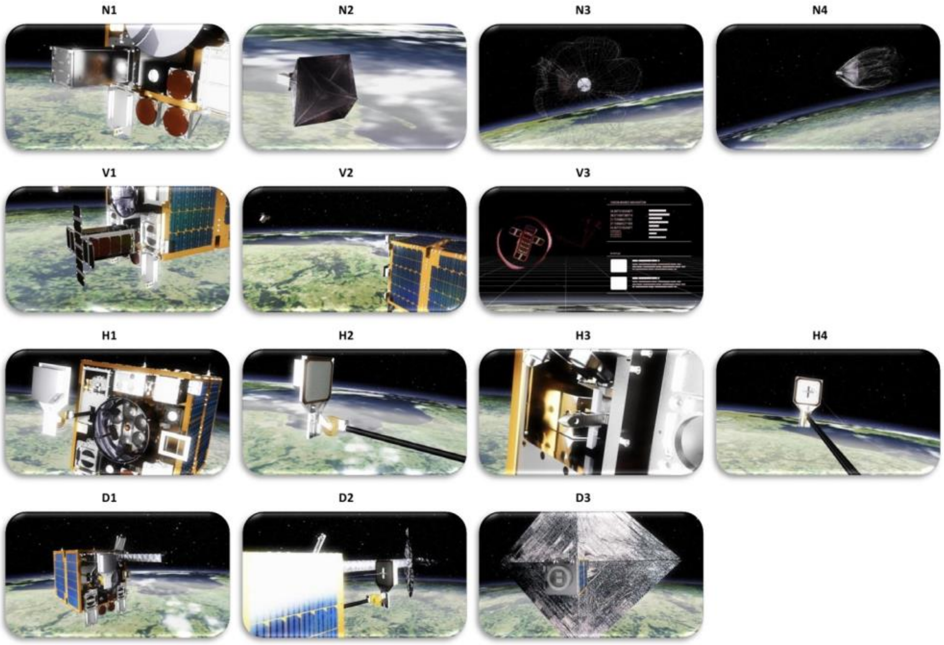

**Figure 2. N1 to N4: net experiment, V1 to V3: vision-based navigation experiment, H1 to H4: harpoon experiment, D1 to D3: dragsail experiment.**

**Table 1: RemoveDebris Mission Chronology**

| Event | Description |
|---|---|
| Launch | Launch of RemoveDebris Spacecraft to ISS on Dragon CRS-14 resupply mission (2nd April 2018)<br>Unpacking of Spacecraft from Dragon Capsule |
| Deployment | Loading of RemoveDebris Spacecraft into JEM airlock<br>Spacecraft Grasped by KABER arm and deployment from ISS |
| Platform Commissioning | Platform power up and initial AOCS operation<br>Operator subsystem/system commissioning |
| Net Experiment | Deployment and inflation of DS-1 CubeSat<br>Deployment of Net and capture of DS-1 |
| Visual Based Navigation Experiment | Deployment of DS-2 CubeSat, transmission of imagery and attitude/position data<br>Observation of departing DS-2 by VBN payload |
| Harpoon Experiment | Deployment of Harpoon Target on end of boom<br>Firing of harpoon into target<br>Retraction of boom, target and harpoon |
| DragSail Experiment | Deployment of Inflatable Boom and Sail<br>Accelerated deorbiting of spacecraft |
| End of Life | Burn up on Re-entry |

## PAYLOAD DEVELOPMENT AND TESTING

This section provides an overview of the development and testing campaigns for each of the payloads [7, 8, 9 10, 12].

### *Visual Based Navigation and active target*

The Vision-Based Navigation is an experiment of proximity navigation between the satellite platform and a CubeSat, designated DS-2 [3]. At the beginning of the experiment DS-2 will be ejected by the platform and will drift gently away for several hours while the attitude is controlled to maintain a slow rotation. The main goal of the experiment is to evaluate navigation algorithms and a VBN sensor. The DS-2 CubeSat is a fully functional system and acts as an active target with integrated camera, GPS receiver and Intersatellite link. In this way, the VBN will capture navigation data of the position, orientation and relative velocity of the DS-2 CubeSat, which can be verified by the data and images captured by DS-2 and transmitted back to the mothership.

Dedicated image processing and navigation algorithms have been designed at Airbus Defence and Space and INRIA to meet the specific case of non-cooperative rendezvous[2]. Airbus Defence and Space is responsible for the overall VBN experiment and the navigation algorithms, while CSEM is in charge of the sensor.

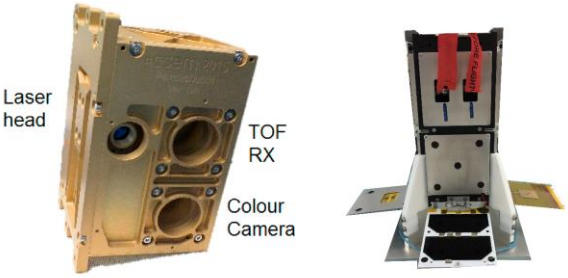

**Figure 3. Left: Vision Based Navigation payload, Right: DS-2 target in deployed state**

The University of Surrey have supplied the DS-2 target CubeSat with an attitude control system supplied by the University of Stellenbosch. The VBN sensor has two main subsystems: an off-the-shelf colour camera and a flash imaging Light Detection and Ranging device (LiDAR) developed by CSEM. Its main functionality is to capture images of DS-2 with both vision-based devices according to a predefined timeline defining snapshot times and integration times.

Figure 5 presents an image captured with the camera. The respective distance of the targets are quoted on the image. Below this, the figure presents the same scene captured with the LiDAR. The LiDAR provides 2 images: a B&W intensity image similar to any standard camera, and a distance image or depth map that is a 3D image of the scene of interest or target. Performance requirements are verified by ensuring the hardware is capable of collecting the requisite number of images. The way in which the VBN algorithms are validated with respect to the VBN experiment and the tracking performance have been investigated in a separate paper[3].

Once integrated with the platform, the VBN experiment was verified through the system chain including transfer of images to the Payload Interface Unit (PIU) and transfer to operators.

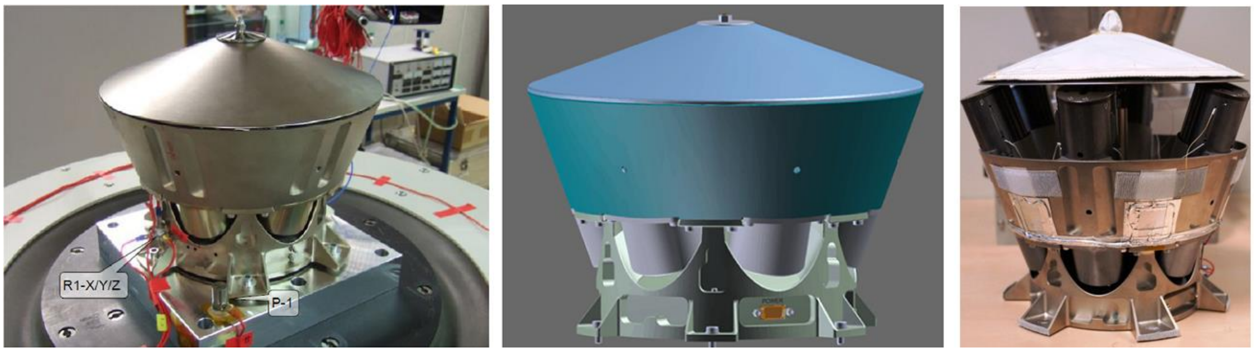

**Figure 4. Left: NET undergoing vibration testing, Centre: NET CAD model; Right: Partially deployed system exposing flight weights.**

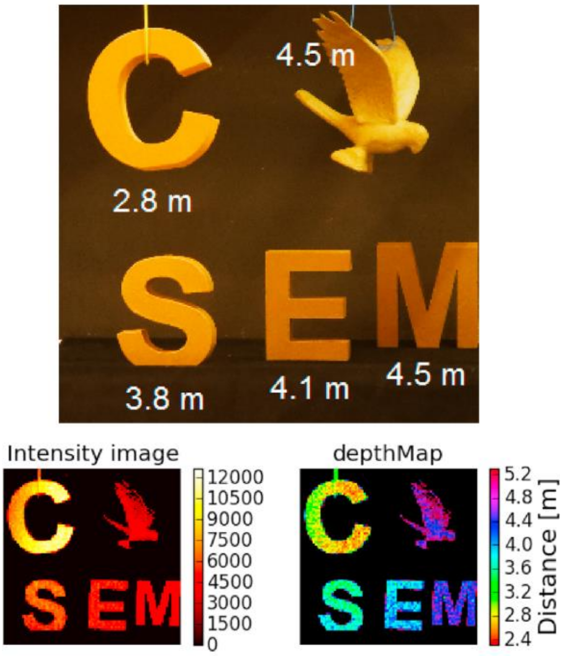

**Figure 5. Top: test scene for VBN system, Bottom Left: showing image intensity in number of visible photons (more yellow objects are brighter). Bottom Right: 3D depthmap scene in metres.**

The DS-2 target CubeSat includes an inter-satellite link (ISL), with a matching module integrated on the platform to collect data from the target. DS-2 streams GPS position, attitude data, imagery and general system telemetry one way over the ISL. On the platform, the ISL data is in turn streamed to the spacecraft PIU. Prior to integration, the ISL subsystems were extensively range tested on ground up to 500m with a 99% packet transfer success. Further, once integrated in to DS-2, the system was demonstrated at representative departure velocities performing all functions and streaming imagery and GPS location as expected on orbit.

**Figure 6. Images captured and transferred during DS-2 integrated CubeSat range testing**

### *Net Experiment and Inflatable Target*

The NET payload will be the first in-orbit flight demonstration for a system catching large orbital debris via a high strength net. On the RemoveDebris mission artificial orbital debris of 2kg and 1m diameter will be captured, however, the 5m net used for this demonstration is already capable to capture debris in the 1.5m range and to return up to several hundred kilograms to Earth on a destructive trajectory. This experiment will be the next big step after successful demonstrations of the net deployment in both drop tower and on a parabolic flight.

The NET design is shown in Figure 4. The NET has 275mm diameter and a height of 225mm. The total mass is 6kg.The high strength fiber net is deployed by concentric accommodated flight weights and a central lid, dragging the net. Motors and winches integrated within the weights are used to close the net after successful capture of the debris. The net deployment and closure will be achieved via redundant mechanisms. The NET will be released to capture the DS-1 debris target at 6m distance from the spacecraft.

Due to the complex dynamics of nets in microgravity, the NET has been tested on parabolic aircraft flights as well as a drop tower to verify correct opening and closing of the net.

As shown in Figure 2, the N2 stages involve the CubeSat, DS-1, deploying an inflatable sail system. The inflatable structure is constructed with five aluminum-polymer laminate cylindrical booms, with an average length of 45 cm. A set of four triangular polyester film segments or sails finish the structure. Initially the booms and sail are compacted into the satellite. The cutting of a burn-wire releases the booms and sail, whereby Cool Gas Generators (CGGs) activate to deploy the booms and side plates outwards and draw out the sail material. The central hub contains the un-deployed z-folded booms which are a two layer aluminum-PET membrane. To prevent the membrane from detaching during pressurization the ends of the booms are clamped between two aluminum disks. The principles of the deployable inflatable for the DS-1 experiment are explained in more detail in a separate paper[4]. The DS-1 CubeSat is electrically simple compared to DS-2, with only a power system and automated payload board to perform burn wire and CGG initiation. Repeated testing of the inflatables was performed to verify performance, including activation at the cold extreme case.

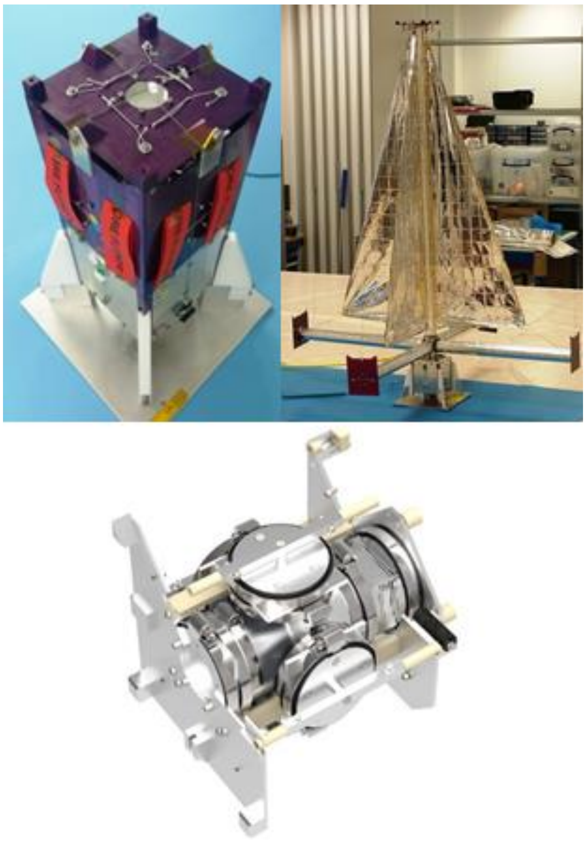

**Figure 7. Top Left: assembled DS-1 flight model (fully integrated). Top Right: fully inflated structure which resembles a pyramid, during SEET testing. Bottom: central inflatable hub.**

Figure 7 shows three images: the full CubeSat with the inflatable packaged inside, the fully deployed inflatable and the central hub inside the CubeSat.

### *Harpoon and Deployable Target*

The harpoon target assembly (HTA) is shown in Figure 8 and contains: structure, deployable boom mechanism, two frangibolts, target plate, harpoon and safety door. The full operation of the harpoon system has been detailed in other papers[5,6]. The sequence for deployment of the target plate is as follows. Initially the target plate frangibolt is cut to release the outer plate. Then the Oxford Space Systems (OSS) deployable boom system is commanded to reel out the boom. The target plate is fixed to the end of the 1.5 meter boom and is pushed outwards. The OSS boom system consists of a carbon fiber boom rolled into a circle and unrolled outwards with a motor and guiding mechanism. Sensors are able to determine the length of the boom uncoiled and retraction is also possible, but not used on the RemoveDebris mission.

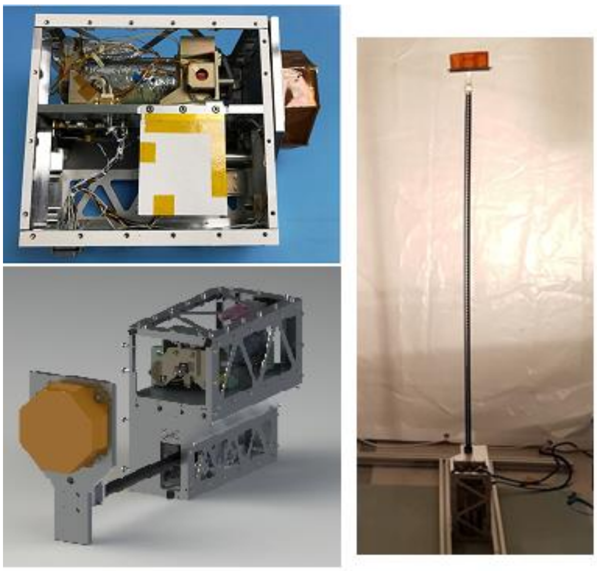

**Figure 8. Top Left: inside the Harpoon target assembly (HTA); Bottom Left: CAD model of HTA with target partially deployed. Right: HTA with CPRF boom fully deployed during fire testing (HTA at bottom, target plate at top).**

Figure 8 shows the fully deployed boom system. Careful alignment is made on ground to ensure the harpoon is aligned with the center of the target plate through use of a laser substituting for the harpoon. The plate is made of a metal honeycomb and is the same material the core of ESA's Envisat satellite is made of.

Several iterations of the design of the harpoon have been performed to provide optimal performance in penetration and retention in the target. The evolution of the harpoon is shown in Figure 9.

**Figure 9. Harpoon projectile prototypes and evolution.**

The testing of the deployment posed some challenges as the boom is relatively flexible and when fully deployed (cantilevered) with the mass of the target at the end, gravity produces a significant effect. The harpoon was tested firing both horizontally at short range and vertically upwards as an integrated system[6]. The plan for the mission is to retract the target after the harpoon has been fired and will be imbedded in the target.

***Dragsail Experiment***

The dragsail [4] consists of two parts: an inflatable mast and a sail deployment mechanism. The system utilizes a 'jack-in-the-box' deployment method in which the ignition of a cool gas generator (CGG) inflates the folded mast, and pushes the stored sail and its deployment mechanism out of the CubeSat structure. The electrical drive system is identical to that used in the DS-1 CubeSat.

The inflatable cylindrical mast consists of a tough aluminium-BoPET three-ply laminate. A BoPET bladder is used inside the cylinder to improve airtightness. The 1 m long, 90 mm diameter cylinder is inflated by a CGG to a pressure of approximately 50 kPa, which is sufficient to cause permanent stretching deformation in the metal plies of the laminate. The inflation gas is then vented in a symmetric pattern. The resulting unpressurised rigidized cylinder has been shown to withstand compressive loads up to 50 N, and bending moments up to 2 Nm[7]. The inflation system consists of two CGGs, each containing approximately 4 g of nitrogen gas. Each of the CGGs is capable of fully deploying and rigidizing the inflatable mast, with two CGGs being included for redundancy. Once full mast deployment and rigidisation has occurred, the inflation gas is vented symmetrically through a valve to prevent potential destabilization due to punctures of a still inflated structure. The system also performs a vent between each CGG activation to avoid over-pressurization of the system in the nominal case of both CGGs activating. The sail is then deployed using a brushless DC motor stored in the central shaft of the sail deployment mechanism which unfurls 1.5 meter carbon fiber booms, drawing the sail out. A separate paper provides greater details on the CPRF booms[8].

The RemoveDebris dragsail system in Figure 10 is very similar to the one which was integrated in the satellite Inflatesail, which was successfully flown and deployed in 2017 [10], shown in Figure 11. The bottom part is the sail deployment mechanism with deployable carbon fiber booms, the middle is the sail material that is drawn out during sail deployment, and the top part is the inflatable rigidisable mast that is deployed to offset the sail from the main platform.

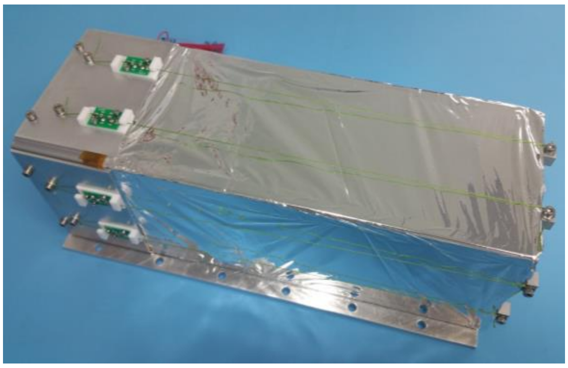

**Figure 10. Top: Integrated FM Drasail; Bottom: Deployed EM system**

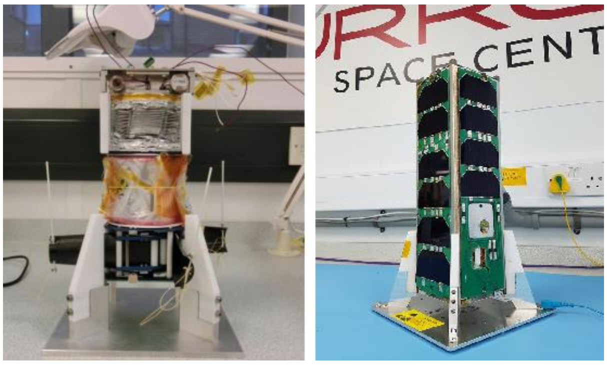

**Figure 11. Left: The complete InflateSail Payload Showing the CFRP Booms (bottom), the Z-Folded Sail Membrane (middle) and the Origami Folded Inflatable Mast with CGGs (top); Right: The integrated InflateSail CubeSat**

Several functional tests were performed in inflating the boom and deploying the sail. Initially, inflatable deployment was tested for maximum pressure, under gravity compensation using both Helium balloons and pulley systems. The removal of the major creases in the skin was clearly observed, showing boom rigidisation. A full complement of environmental testing including vacuum, vibration and thermal were performed. The purpose of the vacuum environmental testing was two-fold. One of the aims was to assess the likelihood of a pressure build-up during ascent to simulate the launch phase and to ensure the solenoid venting valve was correctly operating (the solenoid valve is a normally-open type, so the stowed boom is free to vent until the valve is powered). Secondly, the test helped ensure that the system is airtight in space. During the vacuum testing, a full deployment of the mast was undertaken.

## PLATFORM AND SPACECRAFT SYSTEM TESTING

The RemoveDebris satellite platform is based on the X50 satellite and utilizes internally developed avionics systems under the Fireworks programme[10]. The X-Series platforms are being developed with some key drivers and principles in mind. These are a combination of (a) principles that SSTL have employed successfully in delivering small satellites in the last 30 years, and (b) new approaches that are enabled by SSTL's evolution as a company in the last 15 years, specifically the recently developed in house capabilities for batch/mass production and automated test.

The Removedebris platform has been modified to be compliant for ISS deployment including battery and activation safety features consisting of apply before flight items to be added by astronauts and additional delayed start-up system safeties. Further, certain elements of software for activation of payloads are to be uploaded once deployed from the ISS, rather than included at launch to ensure potentially dangerous commands cannot be sent be spurious commanding whilst in proximity to the ISS.

Once the payloads and satellite subsystems were delivered and accepted into assembly, integration, and test (AIT) facility the satellite underwent a conventional environmental test (EVT) campaign comprising of: EMC testing, mass property measurements, launch box integration and strip down, vibration testing, external inspections, spacecraft functional tests, thermal vacuum testing, integration of flight battery and some flight payloads, EVT results review. At various stages during the test campaign the satellite underwent system level functional tests to ensure the system continued to operate as expect.

### *Spacecraft Safety Reviews*

Launching to the ISS requires NASA safety reviews have to be passed. NASA impose certain constraints on the overall platform design to ensure safety to the astronauts on the ISS. As well as more common requirements, such as the platform not having sharp edges, several other requirements have introduced extra design effort in to the mission. These are detailed as follows. After ejection from the ISS, the main platform is inert for up to 30 minutes before booting on. This is to protect the ISS from interference, or in case of any issues. All batteries on the mission must have triple electrical inhibits and thermal runaway protection. This includes the main platform battery and the two batteries in the CubeSats. The CubeSats also can only turn on when three separate deployment switches are activated, which is only physically possible when the CubeSats have left their respective pods. Mechanically, all the payloads require an inhibit system. Significant effort has been extended to ensure astronaut safety. The harpoon can only fire with an 'arm and fire' sequential command sequence (which would of course require power to the system - which already has a triple electrical inhibit). Without this command, there is no way the cold gas generator (CGG), which propels the harpoon, could be powered, and thus no way in which the harpoon could fire. Furthermore, the safety door in front of the harpoon only opens before firing and must be manually commanded to be opened. In front of the safety door is the main target plate which presents another mechanical barrier.

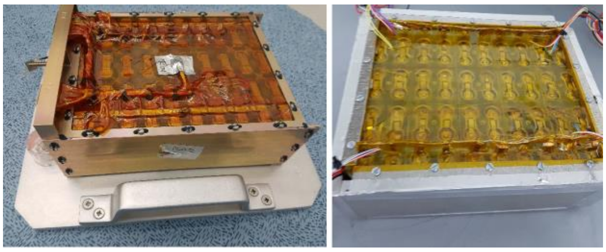

**Figure 12. Left: ABSL supplied RemoveDebris Flight Battery; Right: SSC produced Thermal Runaway Test Battery**

Additionally, the RemoveDebris battery is the largest non ISS system battery to be shipped to the space station, as such the safety of the battery is of paramount importance. The RemoveDebris platform uses an 80 cell battery supplied by ABSL consisting of 1400mAh SONY US18650S in a 8s10p configuration. ABSL are market leaders in the manufacture and qualification of spacecraft batteries and have performed extensive tests demonstrating the safety of their batteries. However test results for the exact 8s10p configuration were not available and so a test battery was produced by the SSC to demonstrate battery safety under thermal runaway conditions. In the extremely unlikely event of the failure of a single cell in to thermal runaway and further failure of cell level protections, it was required to demonstrate no propagation would occur to neighboring cells and result in a chain reaction.

The Thermal Runaway test battery was assembled using Samsung 26F cells due to unavailability of the flight battery cells and selected based on the similar chemistry and constitution of the cells. Corner cells of the battery were induced in to thermal runaway by heating with a wrapped constantan resistance wire on 6 tests. One of these test showed propagation to neighboring cells. On analysis of all test results and build processes this propagation was confirmed to be the result of differences in the cells used to the flight cells (thinner cell casing) and battery construction (blocking of vent path) leading to a rupture of the side of the cell which is not a realistic scenario for the flight battery. An induced thermal runaway event on the test battery can be seen in Figure 13.

**Figure 13. Test Battery induced into thermal runaway**

## LAUNCH, DEPLOYMENT AND OPERATIONS

The launch sequence for the RemoveDebris mission is an unconventional one [5, 6]. The solution uses NanoRacks as a supply agent to launch the final flight platform to the International Space Station (ISS) abroad a SpaceX Dragon capsule. The mass of the platform, 100 kg, represents a new business line, in that past NanoRacks launches of systems from the ISS were of a much lower mass. The use of the ISS scenario, launching to approximately 400 km, provides greater confidence to licensing agencies as to the mission safety, as if there were any issues, all the items would de-orbit very quickly. Additional papers give more information about the orbital lifetime of the objects calculated using both STELA and DRAMA, specialist end-of-life tools[10,11]. They show that the main platform de-orbits within 2 years, even in case of the dragsail not deploying; smaller items, such as the CubeSats, de-orbit within a matter of months. Thus no further space debris is generated.

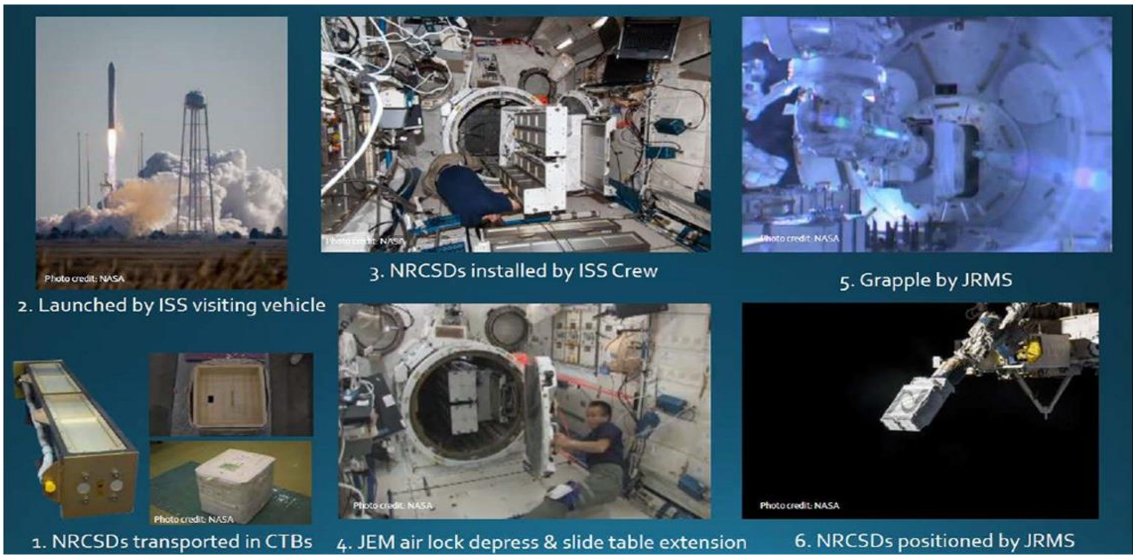

Figure 14. RemoveDebris launch and deployment sequence

### *Shipping and Flight Preparations*

Figure 14 shows the steps involved in launch and deployment of the mission. The RemoveDebris platform was loaded on to the CRS-14 Dragon as cargo in the pressurized section. The main platform is protected by a series of concentric encasements for shipping. Firstly cover panels screw into the platform structure and protect the solar panels. Secondly the paneled structure is placed within a clam shell. This clam shell is placed into a metal protective box and the box is put into the shipping container. On arrival at the launch facility, the platform is unpacked down to the clam shell and the clam shell is loaded into a cargo transfer bag (CTB) (1) and then on to the Dragon for launch (2). Once docked, the satellite is retrieved by astronauts, which install the platform on to the Japanese experiment module (JEM) air lock table (3). The air lock then depresses and the slide table extends (4). The platform is grappled by the JRMS, a robotic arm system (5). Finally, the robotic arm positions and releases the platform into space (6), where commissioning and main operations of the mission can commence. The ejection trajectory ensures that the satellite will not intersect the ISS orbit at a later time. At time of writing, the spacecraft is on the ISS awaiting deployment.

## CONCLUSION

This paper has presented the Surrey Space Centre led RemoveDebris mission, and provides an update on the status of the RemoveDebris mission and the development and testing of the payloads and platform.

The RemoveDebris mission, now in space, will be the first demonstration of key ADR technologies crucial to ensuring a space environment safe from space debris.

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### *References*

1. H. Stokes, *Space Debris - Encyclopedia of Aerospace Engineering - Klinkrad - Wiley Online Library*. John Wiley & Sons, Ltd, 2011.
2. 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.
3. Yol, E. Marchand, F. Chaumette, K. Kanani, T. Chabot, Vision-based navigation in low earth orbit, in: i-SAIRAS 2016, Beijing, China, 2016.

4. 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.

5. 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.

6. 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

7. 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

8. 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

9. Fernandez, J., Viquerat, A., Lappas, V. and Daton-Lovett, A., “Bistable Over the Whole Length {BOWL} CFRP Booms for Solar Sails”, *Advances in Solar Sailing*, Springer. 2014

10. 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

11. 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 Astronaut. 127 (2016) 448–463, http:// dx.doi.org/10.1016/j.actaastro.2016.06.018.

12. E. Joffre, J.L. Forshaw, T. Secretin, S. Reynaud, T. Salmon, A. Pisseloup, G. S. Aglietti, Removedebris - mission analysis for a low cost active debris removal demonstration in 2016, in: 25th International Symposium on Space Flight Dynamics (ISSFD), Munich, Germany, 2015.