# Net Capture Mechanism for Debris Removal Demonstration Mission

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## ABSTRACT

It has been shown that debris removal missions are mandatory in order to secure future access to Low Earth Orbits [1]. In 2017 the Remove Debris mission cofinanced by the Research Executive Agency (REA) of the European Union will verify various key technologies for debris removal. During the on orbit experiment an artificial debris satellite of roughly 1 m diameter will be captured. The net capture mechanism which is one of the demonstration payloads was developed by Airbus DS in Bremen.

The demo capture system features all aspects of a real mission capture process including deployment of a hemispherical 5m net, tether line deployment, active net closure and locking.

The paper will address the primary design aspects, the key parameters and material selections for the system and the qualification and acceptance. The acceptance phase of the net payload was finished in June 2016.

#### **1** INTRODUCTION

Many studies of the last decade have shown that removal of debris removal is mandatory in order to secure future access to Low Earth Orbits (LEO). At the same time several different technology concepts, like means to capture, relative navigation technologies or drag augmentation devices have been developed, which are key elements for future debris removal missions. However, those technologies have never been proved in space as yet, which would be as important to secure the technology maturity for future missions.

In 2017 the Remove Debris mission co-financed by the Research Executive Agency/ European Union will verify various key technologies for debris removal. The net capture mechanism is one of the demonstration payloads and was developed by Airbus DS in Bremen. The net system is one of the most promising debris capture concepts featuring a high degree of flexibility for a broad variety of object shapes, sizes and tumbling rates, i.e. it is well suited even for non-cooperative targets.

The present demonstrator system is designed to capture objects up to 2 m average size. During the on orbit capture experiment an artificial debris satellite of roughly 1 m diameter will be captured. Thus, there are enough margins to tolerate deviations of net pointing.

Future up-scaled net based systems would be capable to capture objects up to 12 m in size. The net capture system is relying on deployment masses which are accelerated in order to pull the net out of a container and to inflate the net on the way to its target object. After capture the net is wrapped around the target and a connection is established via a tether line to change the target object's orbit.

The net capture system of the Remove Debris Mission will validate all functions of a real debris removal mission, including the ejection of a large hemispherical net, the pull-out of a tether line and motorized closure of the net.

The paper will address the primary design aspects, the key parameters and material selections for the system. The net qualification and acceptance test approach is outlined in more detailed.

The qualification phase of the net payload was finished in June 2016. The actual demonstration mission is planned to be launched at the end of 2017.

## 2 REMOVE DEBRIS MISSION

#### 2.1 **Project History**

The Remove Debris project was initiated in October 2013. It is co-financed by, the European Community via the Research Executive Agency and coordinated by the Surrey Space Centre. Various technology demonstration payloads will be hosted on a SSTL (Surrey Satellite Technology Limited) provided bus (see Fig. 1). Nano Racks LLC is providing the launch opportunity via the International Space Station.



Figure 1: Remove Debris Platform [2]

## 2.2 In-orbit Demonstrations

The Remove Debris Spacecraft will be transferred via the JEM airlock and released via robotic manipulator. Approximately 30 min after ejection, i.e. in a safe distance to ISS - the satellite bus will start it's check-out and demonstration phase. The experiments are mainly performed sequentially; with data from each being downlinked before the commencement of the next experiment. The mission demonstrations are expected to take approximately half a year.

In the following, the focus is on the net capture experiment. The other demonstrations are discussed briefly, only.

#### 2.2.1 Net Experiment

The net experiment shown in Fig. 2 shall demonstrate the capture of an artificial piece of debris. The demonstration starts with the release of the so-called Debris-Sat 1 (DS-1 provided by SSC), a nanosat acting as our artificial debris object (see Fig. 3). The DS-1, which is moving with a low velocity (5 cm/s), is inflated to provide a more realistic target size of roughly  $\emptyset$  1 m (see Fig. 4). The net is ejected from the platform when DS-1 is at a 6 m distance (see Fig 5). Once the net (now spread out to 5 m) hits the target, the deployment masses at the end of the net wrap around and entangle with the target. Eventually, motor driven spools reel in the neck of the net preventing re-opening of the net, implemented by direction locking clutches (see Fig. 6). For this capture demonstration the tether line intended to pull the target is not connected to the satellite, because the satellite has no propulsion system, to perform target stabilization manoeuvers. Instead the CubeSat inside the net is left to deorbit at an accelerated rate due to the large surface area/ low ballistic coefficient of the inflated DS-1. During the net demonstration, two supervision cameras record images which are downlinked afterwards to ground to assess the sequence and the success of the net demonstration.



Figure 2: Net Capture Demonstration [2]



Figure 3: Debris Sat 1 Release [2]



Figure 4: Debris Sat 1 Inflation [2]



Figure 5: Net Deployment [2]



Figure 6: Net Closure [2]

# 2.2.2 Harpoon (HTA) Experiment

The harpoon will be fired on a deployable target that extends outwards from the platform. The flight of the harpoon and the unwinding of the tether are observed with a camera.

#### 2.2.3 Visual Based Navigation

The Visual Based Navigation System (VBN) is observing a second piece of artificial debris, the Debris-Satellite 2 (DS-2). DS-2 is observed with cameras during the slow departure and its distance and attitude will be determined from the images. DS-2 is equipped with a GPS system; the data are transmitted to the bus via inter-satellite-link for validation.

The VBN will be operated during the net demonstration as well to check the system and to provide additional images for the net capture demonstration. As the VBN camera has a smaller field of view then the supervision cameras better images are expected at large distance.

# 2.2.1 Drag Sail

The last Demonstration of the mission is a drag sail developed by SSC, being deployed to speed up the decay of Remove Debris.

# 2.2.2 Debris Sat Ejection

The two artificial debris sats are release by cube sat dispensers provided by ISIS. The release mechanism was adapted for this mission in order to provide very slow deployment velocities in a range of 2 to 5 cm/s.

# **3** NET CAPTURE MECHANISM

The idea of a net capture system was invented more than 10 years ago. The concept of the net capture system is shown in Fig. 7.



Figure 7: Net Capture System

Deployment weights which are connected to the circumference of the net are ejected to pull out the net and deploy it to the size required for the capture of a debris object (see Fig. 2). A tether line connects the net with the service spacecraft. Usually, the net gets tangled up with parts of the debris object which can then be safely de-orbited via pulling the tether line.



Figure 8: Deployment weight

To increase reliability in view of the debris removal mission cost and the risk due to a wrong re-entry point the net capture system needs a feature to close the net. This shall prevent an un-intended release of the captured object. In the remove debris mission motors which are accommodated in the weights are operating a spool (see Fig. 8).

The spool is pulling a line to close the net and thereby securing the object inside the net. Fig. 9 shows the 6 FM deployment masses and motors during integration.

The Remove Debris Net Capture Mechanism is using a special technology to release the net: the cover of the net container is holding the deployment weights during launch. For operation only the cover is released, which in turn releases the weights likewise (see Fig. 7 and Fig. 10).

#### 4 SYSTEM RELIABILITY

Although, the net principle function is rather simple, considerable effort has been taken to guarantee a high reliability of the system. The major element was testing which is detailed in Section 5. The other part is redundancy. There is no function inside the net capture mechanism which is not redundant. The hold down and release system is redundant and activated via two completely independent power systems in the net capture mechanism and via independent power lines from the satellite bus.



Figure 9: Deployment weight integration

The closure system comprising six motors and spools (one in each weight) can tolerate the single failure of any of the six motors and can also tolerate the failure of two motors provided they are not adjacent. Even if they are adjacent the degree of net closure would be degraded by 3%, only, which would be irrelevant for a capture mission. The reliability of the net is even better: due to the high strength of the Dyneema fibre a structural failure of the lines is not credible. In fact, the Remove Debris net - which is supposed to capture a 2 kg target - is strong enough to handle up to 8 metric ton targets.

Although, the target object in the Remove Debris Mission is inflated to roughly  $1 \text{ m} \emptyset$  the net mesh size is approximately 0.1 m to guarantee capture even in case of failure of the target inflation system.



Figure 10: Flight Model, ejection springs unloaded

# 5 SYSTEM DEVELOPMENT AND VERIFICATION

The EU-Co-Funded Remove Debris project started in October 2013, however, parts of the concept had been developed and tested in simplified versions by Airbus DS before.

The principle of the deployment was tested during drop tests in a high building in 2008 and the closure concept was tested in a lab rig in 2009 (see Fig. 11).



Figure 11: left net drop test; right net closure test

In 2012, the satellite capture and net deployment concept was tested for the first time in vacuum and 0-g environment in the Bremen drop tower (see Fig. 12).

In the same year the net deployment and closure concept was tested in 0-g conditions in a DLR parabolic flight operated by Novespace (see Fig. 13). Thus, when

the main development was started in 2013 all subsystem concepts had been verified by multiple tests before.



Figure 12: left net deployment in drop tower; right target capture



Figure 13: Parabolic flight test campaign

The design is based on a few clear requirements which were agreed within the Remove Debris team:

- i. Compatibility with a variety of standard launchers (the ISS option developed later in the project)
- ii.  $5 \text{ m} \emptyset$  net to be accommodated inside
- iii. net capture system
  - a. diameter < 300 mm,
  - b. height < 250 mm
  - c. total mass < 6.5 kg
- iv. Capable to capture a 1 m Ø object in 5-7 m distance.

The net capture team decided to manufacture nearly all parts from metal and particular decided to manufacture parts like the net container with a 5-axis-machine (see Fig. 14) from one piece of raw material to avoid snag points for the net.

The design focus was on the net capture, i.e. all features which are not directly related to this challenge were designed as simple and reliable as possible. This approach was essential to limit spending (important for a low cost mission) and at the same time increase system reliability. All functions were first implemented in an Engineering and Qualification Model (EQM) and thoroughly tested before the manufacturing, assembly and testing of the Flight Model were started.



Figure 14: FM components left and QM assembly right

After testing of the basic functions the EQM had to pass a standard vibration test (quasi-static and random loads) (see Fig. 15).



Figure 15: EQM vibration test

Eventually, the net deployment was ground-tested in vacuum and 0-g conditions. This test could be performed partially, only, limited by the net size. There is no ground facility in the world available to deploy a 5 m net in vacuum and 0-g.

For the remove debris net test the Bremen drop tower was used, offering a large, evacuated volume on ground. The test was performed in the lower section of the drop tower and the net was fired downwards from approximately 10 m height in vacuum (see Fig. 16). The deployment could be observed spreading out up to a diameter of 1.2 m before reaching the bottom. Thus, this test verified the first 1.05 seconds of the 3 second deployment sequence. The complete deployment was validated via a numerical simulation. For thermal verification, the EQM was tested in the thermal vacuum chamber between  $-40^{\circ}$ C and  $+60^{\circ}$ C.

For mechanism verification a net release was performed at temperature extremes, both with single as well as redundant release.

The FM net capture system was vibration tested with similar load levels as for qualification. However, a deployment test in the drop tower was not performed with the FM to avoid potential damage by approaching the bottom of the tower. The thermal vacuum test was performed with a reduced temperature range (-20°C to  $+50^{\circ}$ C).



Figure 16: Net ejection in Bremen Drop Tower

# 6 Satellite AIT

After integration of the net capture system in the centre of the Remove Debris satellite (see Fig. 1) a first functional test will be performed excluding release of the net. Such a test will probably be performed with EQM accommodated beside the satellite and connected via a jumper cable. Then thermal vacuum as well as vibration test will be performed in a test rig simulating the launch conditions, i.e. the packaging in foam.

Eventually, the system will be shipped to the US for integration of the robotic arm adaptation system and for final packaging and integration into the launch vehicle. Presently, a SpaceX launch is foreseen in 2017 with the operational period in 2017/2018.

# 7 CONCLUSION

A net capture demonstration payload has been developed within a low budget project. This challenging task was possible because many very simple breadboards of the subsystems had been developed and tested before. In addition, the concentration on the primary features was important for the success of the development project.

## 8 Acknowledgements

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## 9 References

- 1 Donald J. Kessler, Burton G. Cour-Palais: Collision Frequency of Artificial Satellites -The Creation of the Debris Belt, 1978 Journal of Geophysical Research
- 2 Figures 1-6 taken from *Remove Debris Video* and documents produced by SSC, 2017