ELSA-d – A novel end-of-life debris removal mission: mission overview, CONOPS, and launch preparations

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ABSTRACT

The rise of large commercial satellite constellations in low-Earth orbit (LEO) will lead to an increase in the number of objects in key orbits and will raise the risk of potential collision. Systematic spacecraft end-of-life (EOL) management strategies assuring post-mission disposal (PMD) are required to maintain the utility of key LEO assets. The novel End-of-Life Services by Astroscale demonstration (ELSA-d) mission promises to be a major step forward in proving technology necessary for rendezvous and proximity operation (RPO), capture, and removal of orbital debris. The ELSA-d mission, which is in its assembly, integration and test (AIT) stages and is due to launch in 2020, will demonstrate key technologies and procedures for the rendezvous, capture, and eventual de-orbit of a piece of debris.

ELSA-d will consist of two satellites launched together – a servicing satellite that will perform the RPO and capture capabilities and a small client satellite that will serve as a model for a piece of orbital debris. After launching together, the two satellites will repeatedly separate and dock in orbit, each time showcasing a different capability that will be applicable to the commercial market. The servicing satellite will be equipped with rendezvous guidance, navigation, and control (GNC) technologies and a magnetic docking mechanism, whereas the client has a docking plate (DP) which enables it to be captured.

In this paper, the technologies behind each phase of the concept of operations (CONOPS) and how these align with future servicing missions will be discussed. Whereas previous similar missions have performed RPO with cooperative and stable targets, ELSA-d will demonstrate semi-autonomous capture of both non-tumbling and tumbling targets, the latter being novel in the space environment. ELSA-d will also demonstrate search and inspection capabilities in which we will intentionally place the client satellite outside of the field of view of the relative navigation sensors on the servicer. The use of a walking safety ellipse, a passively safe trajectory, and the combination of sensor scanning and absolute-to-relative navigation handover are key RPO capabilities that will be validated. Additionally, the autonomy of the ELSA-d mission, assessing which aspects are performed autonomously on-board and which are performed by an operator, are described. This will have implications on utilization of both the space and ground segments of future missions.

As ELSA-d is finalized for its upcoming launch, this paper will give an overview of the latest updates from Astroscale Japan’s clean room and provide a description of the technologies that will lead to safe and effective solutions for maintaining orbital sustainability and accessibility of LEO.

1 INTRODUCTION

ELSA-d, which stands for End of Life Services by Astroscale (-demonstration), is an in-orbit demonstration (IOD) for key end-of-life technology and capabilities of future debris removal missions. In Astroscale (AS), end-of-life (EOL) and active debris removal (ADR) have the following distinction: EOL is concerned with removal of future entities that are launched with a docking plate (DP) for semi-cooperative removal, whilst ADR is concerned with removal of existing entities in space that do not have a DP and are fully non-cooperative.

ELSA-d, due for launch in 2020, consists of two spacecraft, a servicer (180 kg) and a client (20 kg), launched stacked together. The servicer is equipped with proximity rendezvous technologies and a magnetic capture mechanism, whereas the client has a DP which enables it to be captured. With the servicer repeatedly releasing and capturing the client, a series of demonstrations can be undertaken including: client search, client inspection, client
rendezvous, and both non-tumbling and tumbling capture. ELSA-d is operated from the UK at the National In-orbit Servicing Control Centre Facility, developed by AS as a key part of the ground segment.

### 1.1 Mission Overview

The ELSA-d mission (also see [1]) is an in-orbit demonstration that aims to test several capabilities and technologies needed for future services. The servicer and client can be seen in Figure 1, showing renditions for both docked and undocked configurations. For the ELSA-d mission, the client, for convenience and mass-minimization, is smaller relative to the servicer than a future EOL or ADR mission. The client is also commandable, ensuring demonstrations can be tested in a simplified manner earlier in the mission. For example, before tumbling capture is attempted, the easier case of non-tumbling capture is attempted which requires the client to hold a set attitude. Because the client is launched with the servicer, the CONOPS can be designed such that the complexity and risk increments gradually. This compares to a full service where the non-trivial task of finding the client would be among the first mission actions. The core constituents of the mission include a rendezvous (RDV) and docking suite and a magnetic capture system. Other elements include classical bus elements, such as power, propulsion, communications and processing. The key features of the mission are summarized in Table 1.

<table>
<thead>
<tr>
<th>Entity</th>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servicer</td>
<td>Structure</td>
<td>~ 0.6 × 1m</td>
</tr>
<tr>
<td></td>
<td>Mass</td>
<td>~180 kg</td>
</tr>
<tr>
<td></td>
<td>GNC (command)</td>
<td>GNC OBC, GNC sensor handling unit</td>
</tr>
<tr>
<td></td>
<td>GNC (sensing)</td>
<td>star trackers, gyros, magnetometers, sun-sensors, accelerometers, GPS</td>
</tr>
<tr>
<td></td>
<td>GNC (actuation)</td>
<td>reaction wheels (pyramid), magneto-torquers</td>
</tr>
<tr>
<td></td>
<td>GNC (RDV)</td>
<td>night cameras, day cameras, laser ranging device, radiometric ranging device, illuminator</td>
</tr>
<tr>
<td>Capture</td>
<td></td>
<td>magnetic capture system</td>
</tr>
<tr>
<td>Comms</td>
<td></td>
<td>S-band, X-band</td>
</tr>
<tr>
<td>Power</td>
<td></td>
<td>deployable double solar array, PCDU system, flight battery</td>
</tr>
<tr>
<td>Propulsion</td>
<td></td>
<td>green propellant chemical propulsion system</td>
</tr>
<tr>
<td>C&amp;DH</td>
<td></td>
<td>BUS OBCs, CAN bridge, spacewire router</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>retro-reflector, client separation mechanism &amp; activation unit</td>
</tr>
<tr>
<td>Client</td>
<td></td>
<td>~20 kg satellite with OBC, EPS, S-band COM, AOCS</td>
</tr>
<tr>
<td>Docking plate</td>
<td></td>
<td>DP mounted on client</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td>retro-reflector, camera, illuminator</td>
</tr>
</tbody>
</table>

Table 1 – ELSA-d: Mission Features
Figure 1 – ELSA-d: Servicer and Client. Top: servicer with attached client. Middle: release of client for a capture demonstration. Bottom: recapture of client with servicer capture system extended.
2 MISSION CONOPS

The mission CONOPS are shown in Figure 2 and are divided into 7 phases. Between demonstration phases, when the servicer and client are docked, they can enter a routine phase which is power and thermal safe. The phases are designed to generally increase in complexity ensuring less risky demonstrations are attempted first.

A video demonstrating the sequences can be seen here: https://youtu.be/HCWxdK7l0hI.

The mission CONOPS is subject to change and designed in a fluid manner that give operators the final decision in spacecraft operations, and making up-to-date decisions about undertaking demonstrations based on satellite health and performance.

![Figure 2 – Mission CONOPS](image)

2.1 Phase 1 to 2: Launch, LEOP and Commissioning

The servicer and client are launched together into the operational orbit of roughly 550 km. The injection orbit and profile are presently in discussion with the launch provider. The servicer undergoes commissioning, testing interfaces with the ground segment, ensuring subsystems (where possible) are calibrated, and resulting in a system ready to start the demonstrations. The client is activated using the client activation unit (TAU) and undergoes the majority of its commissioning prior to separation.

2.2 Phase 3: Capture without Tumbling

A client separation mechanism (TSM) holds the client and servicer together during launch and Phase 3 is the first time the client is separated; once separated, the magnetic capture system is used to repeatedly capture and release the client, so the TSM is no longer in use. The majority of the client commissioning has already been undertaken, so any remaining commissioning is performed. The servicer has the ability to position itself at set distances behind the client, which are defined as specific holding points (these include for example Point A and Point B, 10 m and 5 m behind the client, respectively). At Points A and B, the servicer performs a navigation check-out and calibration using its rendezvous sensors. This is the first time these sensors can be tested in space, since they can’t be tested whilst the client is docked. Finally, the client is commanded to hold a set attitude and the servicer goes in for
capture utilizing the docking plate on the client for guidance. There are several sub-phases of the final capture including client acquisition and tracking, and velocity, position and roll synchronization, but these are easier in the non-tumbling case than the tumbling Phase 4 case.

2.3 Phase 4: Capture with Tumbling
This phase is the more dynamically complex version of Phase 3 where full tumbling capture is performed. The phase also includes a rehearsal to attempt the demonstration before finally going for the final capture. In the demonstration, the client is commanded to follow a natural motion tumbling attitude profile. The servicer performs the sub-phases of final capture listed in Phase 3. Part of the capture involves taking images of the tumbling client which are downloaded to ground and post-processed to extract client attitude. There, the FDS (flight dynamics system) in the ground segment supplies data back to the servicer to create a trajectory to move and orient the servicer with the client such that the servicer is always facing the client DP. The trajectory is executed to align the servicer and client, whereby settling is then used for final alignment before capture. The “dance” is the necessary motion and alignment needed during the tumbling capture.

During the phase, inter-demo C&R (capture and release) is an available option to “pause” demonstrations by quickly recapturing (most likely in non-tumbling capture methodology) if an operator so desires.

2.4 Phase 5: Diagnosis and Client Search
This phase consists of two demonstrations: diagnosis, client search. In the first, the client separates from the servicer and the servicer performs a fly-around in day to inspect the client. Client inspection is a key capability for future missions, where operators will have to analyze the client and make a go/no go decision on capture.

In the second demonstration, an initial client search and approach is simulated. The servicer separates and thrusts away from the client back to a recovery point. The servicer moves into a safety ellipse, simulating first approach to an uncooperative client as in a full service mission. In a full mission, a combination of sensor data, including GPS and ground tracking, is used for the FDS to calculate a trajectory to insert the servicer on to a rendezvous trajectory with the client. In the ELSA-d mission, the FDS is still used but the demonstration is performed off-line. A “client lost scenario” is demonstrated by making the sensors lose the client at long range. The servicer then uses its sensors to reacquire the client and makes the final approach to recapture.

2.5 Phase 6 to 7: Re-orbit and Closeout
In the final phase, the servicer performs a re-orbit maneuver to reduce the client altitude. This simulates the final de-orbit in a full mission. At a lower altitude, after natural decay, the craft is passivated. Both servicer and client proceed to an uncontrolled de-orbit burning up on re-entry. The mission at all times maintains 25 year debris mitigation compliance, as the initial demonstration altitude is only 550 km. The full duration of the mission is expected to last up to 6 months, including non-demonstration (routine) phase periods.

3 TOWARDS LAUNCH
As the design stages have progressed, some adjustments to the mission baseline have occurred since past papers. Compared to the original mission design [7], the mission has been augmented with deployable double solar panels and re-routing of thrusters for higher fuel efficiency.

ELSA-d assembly, integration and test (AIT) is presently ongoing in an Astroscale Tokyo clean room. A comprehensive series of both functional and environmental tests at the subsystem and system level are being undertaken. Figure 3 shows the STM (structural model) in the clean room. This model underwent vibe mechanical testing as part of the EVT flow.

Figure 4 shows the final flight model test flow. Initially TableSat testing is undertaken with a series of functional, interface, fit tests. The Servicer is assembled with all of the key subsystems integrated and bakeout is performed. Moving on to EVT, both TVAC, vibration, acoustic and EMC testing is undertaken. During this process key deployables such as the capture system are tested e.g. extension and retraction tests. Ground segment tests in ensuring communication with the MCC (mission control center) along with separate ground station network
communication tests are undertaken. Finally, full property measurement is undertaken along with any final system end-to-end testing (SEET), before shipping. Presently ELSA-d is being assembled and bake out is underway.

ELSA-d is also progressing through the mission licensing process, with on-going discussion with the UKSA. This is part of the wider exercise of Astroscale involving itself in regulatory, policy and insurance discussions to grow the ADR market [2, 3, 8].

![Image](image.jpg)

**Figure 3 – ELSA-d: AIT.** Assembly, integration and testing for the STM (ELSA-d structural model).

![Image](image.jpg)

**Figure 4 – ELSA-d: AIT.** Test flow.
4 CONCLUSIONS

ELSA-d, which stands for End of Life Services by Astroscale (-demonstration), is an in-orbit demonstration (IOD) for key end-of-life technology and capabilities of future debris removal missions. ELSA-d, due for launch in 2020, consists of two spacecraft, a servicer (180 kg) and a client (20 kg), launched stacked together. This paper has examined key aspects of the mission, including the several phases in the mission CONOPS that demonstrate the following capabilities: client search, client inspection, client rendezvous, and both non-tumbling and tumbling capture. A brief overview of the progress towards launch, including movement through the AIT stages, was also presented.

The ELSA-d mission is an important step towards fully operational EOL and ADR missions by maturing technologies and capabilities necessary for future services. In particular, the ELSA-d mission will not just space-prove future payload technologies but will also go through almost the full series of CONOPS expected in a full servicing mission with a demonstration client.

5 REFERENCES


