ELSA-d CONOPS and Debris Mitigation Overview

The end-of-life (EOL) services Astroscale demonstration (ELSA-d) mission will be commanded and controlled by a UK registered company, Astroscale Ltd. (Astroscale), from a mission operations center located at the Catapult[1] innovation facilities in Harwell, England. The mission will be subject to a mission license, to be obtained from the UK Space Agency, that considers orbital debris mitigation planning and execution. Accordingly, the ELSA-d mission will be subject to direct and effective regulatory oversight by the UK Space Agency,[2] meeting the FCC's orbital debris mitigation rules.[3] Nonetheless, the applicant hereby provides a summary of key elements of the information provided to the UK licensing authority to demonstrate that the debris mitigation plans associated with the ELSA-d mission are consistent with the FCC's rules.[4]

As part of its ELSA-d mission license application, Astroscale has provided information to the UK Space Agency regarding the following subjects:

1. ELSA-d mission description and overview
2. Servicer and client spacecraft descriptions and orbital parameters
3. Safety and mission assurance
4. Debris mitigation
5. Deorbit, passivation, and re-entry hazards

1. ELSA-d Mission Description

a. Overview

Since the beginning of the space era, the amount of debris generated in low-Earth orbit has been steadily increasing. Founded in 2013, Astroscale's mission is to provide reliable and cost-efficient spacecraft retrieval services to satellite operators and others in order to secure long-term spaceflight safety and achieve orbital sustainability for the benefit of future generations.

Astroscale is one of the few companies in the world proposing to aid in the removal of orbital debris through the provision of two services: EOL servicing of low-Earth orbit (LEO) constellations, and active debris removal (ADR) servicing of existing space debris.

The ELSA-d mission will be a major step forward in demonstrating that the Astroscale technology is capable of rendezvous and proximity operations (RPO), capture, and removal of orbital debris. The ELSA-d mission, which is in its assembly, integration, and test (AIT)

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[1] https://sa.catapult.org.uk/.

[2] https://www.gov.uk/guidance/apply-for-a-license-under-the-outer-space-act-1986#applying-for-a-licence.

[3] Non-U.S. licensed space stations can satisfy the Commission's orbital debris rules "by demonstrating that debris mitigation plans for the space station(s) for which U.S. market access is requested are subject to direct and effective regulatory oversight by the national licensing authority. 47 C.F.R. § 25.114(d)(14)(v).

[4] 47 C.F.R. §25.114(d)(14).

stages and tentatively planned to be launched around July 2020, will demonstrate key technologies and procedures for the rendezvous, capture, and de-orbit of a piece of mock debris.

ELSA-d consists of two satellites, which are initially attached during launch, a “servicer” satellite that will perform the RPO and capture and a “client” satellite that will serve as a model piece of orbital debris.[5]

After launch and deployment, the two satellites will repeatedly separate and then dock in orbit, testing and showcasing different capabilities that will be applicable to the commercial market. The servicer satellite will be equipped with rendezvous guidance, navigation, and control (GNC) technologies and a magnetic docking mechanism, and the client satellite will have a docking plate (DP), which enables it to be captured by the magnetic docking mechanism.

b. Mission Phases and Events

The demonstration mission will occur in an orbit between 500 and 600 km altitude (with a nominally target orbit of 550 km), depending on the deployment altitude of the primary mission of the launch vehicle, and have a mission duration of 6 to 12 months.

The mission CONOPS is shown in Figure 1 and is divided into 7 phases. Between demonstration phases, when the servicer and client are docked, the satellites will enter a routine phase, which is power and thermal safe. The mission demonstration phases are designed to increase in complexity, ensuring less risky demonstrations are completed first. A video of the mission demonstration phases is available here: https://youtube.com/HCWxdK7l0hI.

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

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[5] In the UK license application filings, Astroscale uses the terms “chaser” and “target.” However, Astroscale has since adopted the terms “servicer” and “client” in accordance with CONFERS Guiding Principles and uses those terms throughout this document although some graphics within this application may still display the previous naming convention. *See* Consortium for the Execution of Rendezvous and Servicing Operations (CONFERS) Guiding Principles, Nov 2018. https://www.satelliteconfers.org/wp-content/uploads/2018/11/CONFERS-Guiding-Principles_7Nov18.pdf.

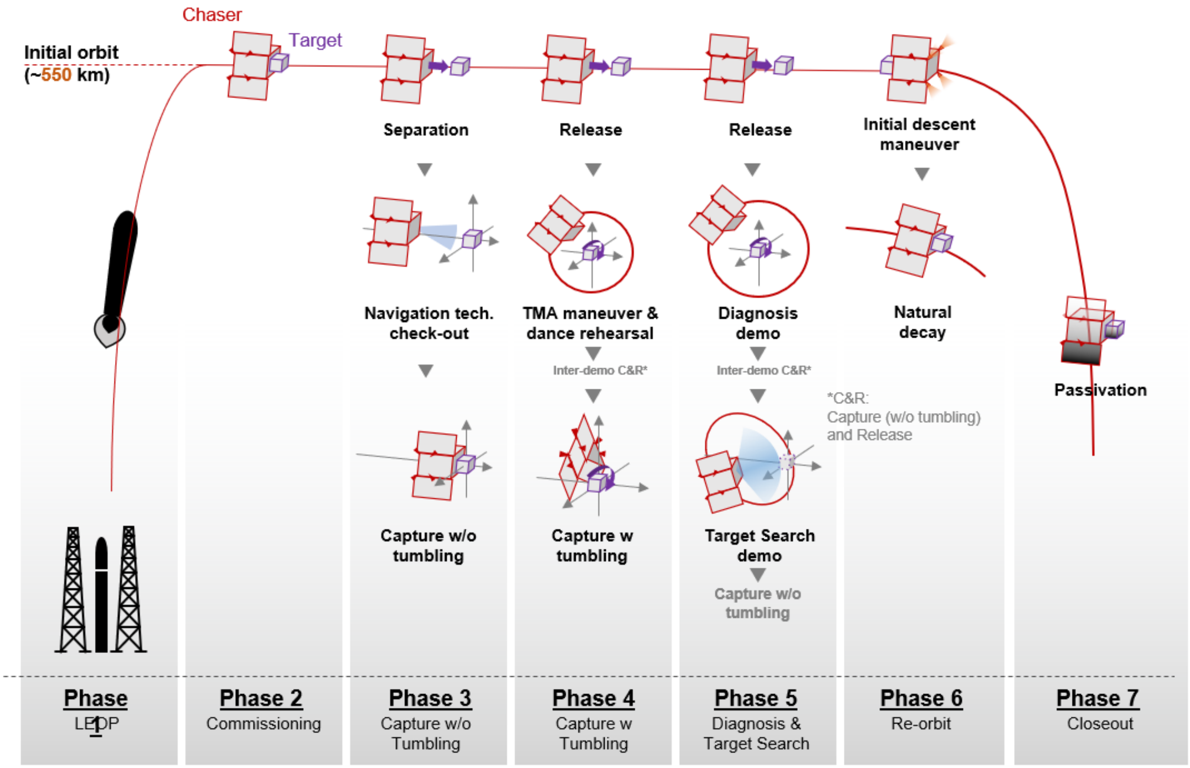

Figure 1: Phased approach to ELSA-d mission

Phase 1 to 2: Launch and Early Operation Phase (LEOP) and Commissioning

The servicer and client, which are physically attached during launch, are launched into an orbit between 500 and 600 km altitude (with a nominal target orbital altitude of 550 km). After deployment, the servicer undergoes commissioning. Among other things, the company will test interfaces with the ground segment and ensure subsystems (where possible) are calibrated. During this phase, the client also undergoes the majority of its commissioning.

Phase 3: Capture without Tumbling

A mechanism holds the servicer and client together during launch. During this Phase 3, the client is separated from the servicer using that mechanism, which would subsequently no longer be used. Once separated, the magnetic capture system on the servicer is used to repeatedly capture and release the client. During this phase, the remaining commissioning of the client rendezvous sensors 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. Finally, the client is commanded to hold a set attitude, and the servicer proceeds to capture the client utilizing the DP on the client. There are several sub-phases of the final capture including client acquisition and tracking, and velocity, position and roll synchronization.

Phase 4: Capture with Tumbling

This phase is a more dynamically complex version of Phase 3, where full tumbling capture is performed. The phase also includes a rehearsal to attempt the demonstration before going for 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 the ground and post-processed to extract client attitude. The Flight Dynamics System (FDS) 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 Capture and Release (C&R) is an available option to “pause” demonstrations by quickly recapturing (most likely in non-tumbling capture methodology) if an operator so desires.

Phase 5: Diagnosis and Client Search

This phase consists of two parts: diagnosis and client search. In the first part, the client separates from the servicer, and the servicer performs a fly-around 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 part, 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 and then simulates a “client lost scenario.” In a typical mission, a combination of sensor data, including GPS and ground tracking, is used by the FDS to calculate a trajectory to insert the servicer in rendezvous trajectory with the client. In the ELSA-d mission, the FDS calculation is 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.

Phase 6 to 7: De-orbit and Closeout

In the final phase, the servicer performs a de-orbit manoeuver to reduce the combined servicer and client altitude. This simulates the final de-orbit phase of a full mission. At a lower altitude, after natural decay, the servicer is passivated. The combined servicer and client proceed to an uncontrolled de-orbit burning up on re-entry, as discussed below in Section 5.c.

As discussed below in the Section 5.a., under nominal conditions with controlled de-orbiting, Astroscale projects a 7-year de-orbit period for the combined servicer and client.

2. Spacecraft description

The ELSA-d mission consists of two objects: the servicer satellite and the client satellite, depicted below in Figures 3 and 4. The servicer satellite will have a mass of approximately 175 kg and the client is approximately 20 kg. Both the servicer and client satellites have attitude control, communications packages, power, battery storage, and sensors. Additional specifications are provided in Table 1 below.

a. Propulsion

Only the servicer has propulsion. The propulsion type is a green propellant, LMP103S, blow-down using 10.5 kg of fuel, and achieves approximately 43 m/s of equivalent delta-V depending on the propulsion mode.

b. Attitude and Orbit Control System

Both the servicer and client have attitude control.

The Servicer Attitude and Orbit Control System (AOCS) main tasks are the following:

- Perform attitude manoeuver to acquire targeted attitude and pointing
- Maintain delta-V direction during orbital and collision avoidance manoeuvers
- Maintain client tracking
- Perform detumbling after client capture
- Perform client approach and capture manoeuvers
- Perform orbital and collision avoidance manoeuvers
- Physical property estimation

The servicer AOCS subsystem consists of the following:

- Control & Interface Electronics
- Attitude Determination Sensors:
    - Star trackers
    - Non-spin sun aspect sensors
    - Geomagnetic aspect sensor
    - Accelerometer
    - Gyroscope sensors
- Orbit Determination Sensors:
    - GPS
- Relative Navigation Sensors:
    - Navigation cameras
    - Laser range finders
    - Low power radars/radio
    - Visible camera
- Actuators:
    - Reaction wheels
    - Magnetorquers
    - Reaction Control System

For the client, the AOCS main tasks are:

- Detumble the satellite after separation from servicer
- Achieve coarse 3-axis nadir control
- Carry out required special mode
- Tumbling
- Controlled rotation

The client AOCS subsystem consists of the following:

- Sensors:
    - Sun Sensor
    - Magnetometer
    - GPS receiver
    - Gyroscope (not used by the AOCS Algorithm proper, but will be used to confirm attitude rates of the client)
- Actuators:
    - Momentum Wheel
    - Magnetorquer
- Algorithm loaded on the client OBC (On-board Computer) (no dedicated OBC)

More detail on the servicer and client is shown below.

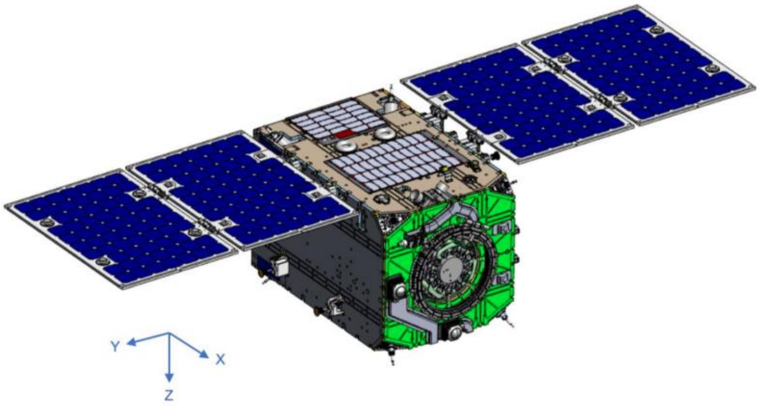

Figure 3: Servicer Body Frame

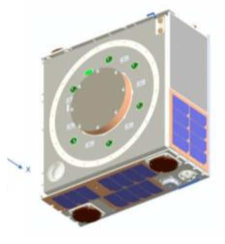

Figure 4: Client Body Frame

Category	Item	Specification
Mission		In-orbit demonstration of semi-cooperative debris capture (rendezvous technology) for future EOL debris removal services
Orbit	Orbit Type	Sun-synchronous orbit (97.6-98.6 degrees inclined)
	Altitude	Between 500 and 600 km (with a target, nominal orbit of 550 km).
	Other Orbit Elements	LTAN 11:00 +/- 0.08 Eccentricity < 0.005
Structure, Mass	Structural Type	Servicer: Panels and Bulkheads Client: Panels and Bulkheads
	Mass	Servicer Wet: 173.5 kg Servicer Dry: 163.0 kg Client: 17.2 kg
Power	Solar Arrays	Servicer: Two double-folded static panels Servicer and client: Body mounted cells
	Power Generation	Servicer: 750 W Max (for nominally sun-pointing side) Client: 9.79 - 10.75 W
	Battery Storage	Servicer: 30 Ah Client: 2600 mAh * 8 cells
Communication	S-Band Uplink	Servicer: 2095 MHz, 4 kbps Client: 2073 MHz, 38.4 kbps
	S-Band Downlink	Servicer: 2275 MHz, 64 kbps (nominal) / 4 kbps (LEOP and emergency) Client: 2251 MHz, 38.4 kbps or 115.2 kbps
	X-Band Downlink	Servicer: 8470 MHz, 8.333 Mbps (25/3 Mbps)
Propulsion	Propulsion Type	Servicer: Green propellant; blow down Client: No propulsion
	Fuel	Servicer: 10.5 kg
	Equivalent delta-v	Servicer: Approx. 43 m/s (max.)
Dimensions		Servicer: 640 x 640 x 983 mm Client: 470 x 470 x 200 mm

Table 1: Design specifications and orbital parameters

The ELSA-d mission is tentatively planned to be launched around July 2020 (date TBC) from Baikonur, Kazakhstan on a Soyuz-2.1a.

3. Safety and Mission Assurance Practices

Astroscale's mission and core purpose is to mitigate the creation of orbital debris in order to create a sustainable space environment. As such, the company is committed to preventing any further generation of debris and is taking measures during the ELSA-d mission to employ safety and mission assurance (S&MA) practices. A full S&MA plan, generally following ISO 14620-1, is in place to inform all aspects of safety in the mission.

The S&MA process includes three Safety Reviews as part of the mission design:

- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- Pre-flight

A separate reliability and quality assurance plan (R&QA) informs aspects such as quality, EEE parts ratings, and a critical item list (CIL).

The mission has been designed with safety in mind, including:

- Oversight and training
- Fault tolerance and redundancy
- FDIR hierarchy
- Elevated control authority
- Heartbeat observation concept
- Protected commanding
- Comprehensive contingency operations

a. Oversight and Training

Oversight and training of personnel is a key element of Astroscale's mission assurance efforts. All operations will be conducted through the dedicated National In-orbit Servicing Control Room, located at the Catapult innovation facilities in Harwell, England. Operators work in a clear organised structure and are trained using a high fidelity simulator to simulate all phases ahead of mission. The mission is made safe through levels of operator control and operational practice such as:

- Ground segment oversight
- Manual experiment abort
- Built in safety demonstrations (contingency demos and C&R)
- High fidelity ground based simulation and operator training

Operators have the ability to manually abort demonstrations at any point. In case of communications failure to/from the ground in critical operations (refer to *Heartbeat Observation*), the mission will automatically interrupt or abort (see *Servicer/Client Abort Collision Avoidance Section 4(b)(ii)*).

The way in which operators handle contingency and safety in the mission is well considered. Operators both train for contingency scenarios in simulation and also have abort capabilities during all mission phases where the client is separated.

Pass coverage is designed to chain ground stations, meaning that ground stations are located around the earth on the ground track of the satellite, so that contact can be acquired for long periods of time. This is handled by the ground segment and pass coverage is booked automatically in advance by the system. This leads to minimal gaps during critical periods.

Mission operations personnel have dual responsibilities with regard to training and rehearsals:

- Ensure they are available for training and rehearsal preparation as required, in order to attain sufficient skills and knowledge as required by their position within the team;
- Provide assistance and training to other team members who may be reliant on their knowledge and past experiences.

The mission manager will coordinate all training, developing an appropriate timetable to ensure the participation of all staff in exercises and rehearsals as necessary. In addition, the exposure of each individual to all mission exercises will be recorded to provide a true record of their training.

Criteria for success of the training will be based upon those involved demonstrating sufficient learning such that:

- The operation is completed in the appropriate time frame without external assistance;
- All time critical events occur at the correct time;
- Simulated spacecraft Health and Safety is not compromised;
- Any anomalous situation is recognised immediately.

b. Fault Tolerance and Redundancy

Full Fault Tree Analysis (FTA) and Failure Modes, Effects and Criticality Analysis (FMECA) has been undertaken to identify the fault conditions and hazards on the mission. This has informed mission safety requirements, Fault Detection Isolation and Recovery (FDIR) design and corrective action for faults, creation of hazard and risk control lists, and operational safety procedures for operators to use in an emergency.

All key systems are single-fault tolerant (a failure in the ground segment or space segment shall not cause a collision between servicer and client).

c. Protected Commanding

Commands are authenticated by the servicer to ensure they are coming from the actual ground segment. This prevents a servicer being hijacked by external parties. MAC code is generated using a key based on packet, and then added to packet trailers. The packet is decoded on arrival to authenticate packet.

d. Contingency Operations

ELSA-d has a full set of contingency CONOPS that specify the steps the mission will take under failure scenarios. The mission can be made safe through both operator control and practice as well as through mission design, as discussed below:

i. Operator Control and Practice

The mission is made safe through level of operator control and operational practice:

- Ground segment oversight
- Manual experiment abort
- Built-in safety demonstrations (contingency demos and C&R)
- High-fidelity ground-based simulation and operator training

ii. Safety in Mission Design

The mission is made safe through the design of the mission (e.g. hardware, software):

- Protected critical functions
- Single-fault tolerant, fail-safe system and architectural redundancy
- Heartbeat for automatic abort during critical phases
- Protected commands & data (authentication)
- Safety critical computing: FDIR and safety tasks

A series of contingency demonstrations will be performed at key points. These will help “practice” for an emergency scenario ahead of one actually occurring:

- 2G - Contingency operations check-out – docked (servicer simulates that there is an imaginary client, and that servicer is in the proximity of client).
- 3G to H - Contingency operations check-out – separated (servicer is commanded from the ground segment to take contingency actions).

ELSA-d can perform inter-demo C&R at key points. In the case when a certain amount of time is necessary in the middle of a phase (for plan-out, timing adjustment, general safety assessments, etc.), the servicer can capture the client without tumbling, before releasing and resuming the phase activities. An operator will decide if C&R is appropriate based on the available data.

4. Debris Mitigation

Limiting and preventing the creation of debris during the ELSA-d mission is of utmost importance. The mission will follow international guidelines and requirements of the UK Government in the limitation of the creation of orbital debris. This includes:

- Limiting release of debris from normal operations
- Employing collision avoidance procedures
- Employing deorbit plans after end of mission

a. Limiting release of debris

Battery charges, voltage and currents, propellant tank pressures and reaction wheel speeds will be monitored during disposal operations. No solid or ionizing or gaseous materials will be released during the ELSA-d mission other than as part of the servicer's normal propulsion system. Although the client satellite is simulating a piece of debris which will be detached from the servicing satellite, it is in fact an operational satellite with communications and attitude-control capabilities.

There is no plan for an intentional breakup of either the servicer or client during this mission.

b. Collision Avoidance

ELSA-d has a clear process for collision avoidance (active and passive aborts) between the servicer and client, and between the servicer or client and other external resident space objects (RSOs).

The way the mission is made safe through design of the demonstrational sequences:

- Collision avoidance manoeuvers (nominal)
- Collision avoidance (passive and active aborts)
- Movement to evacuation point
- Protected safety ellipse

i. Servicer/Client and External RSO COLA

Conjunction data will be provided by the European Space Agency (ESA) pursuant to an agreement, and Astroscale is also planning to work with other third-party space situational awareness providers to further evaluate any conjunction warnings. The command control segment of the ELSA-d mission will include a 24-hour point-of-contact to monitor conjunctions and provide an open line of communication with other orbital "neighbors."

Astroscale has signed an agreement with ESA to exchange data and expertise related to space debris collision avoidance, environmental monitoring of debris and the development of monitoring techniques. Under this agreement, ESA will provide Astroscale with collision assessments for the ELSA-d servicer, including collision avoidance manoeuvre recommendations and screening. ESA will also present a request for tracking support for the ELSA-d servicer and client to the International Laser Ranging Service (ILRS), which will include both the servicer and client on the ILRS' list of objects to be followed.

Astroscale will install satellite laser ranging reflectors on the servicer and client to enable high-precision orbit determination and provide GPS measurements at least twice a day. The agreement also provides ESA with access to camera time over three observation periods. The camera will be used to test the principle of detecting small pieces of space debris crossing the field of view, which will generate important data to be used by ESA in developing a future, larger optical instrument. ESA and Astroscale will further work together on the feasibility of the observation approach and identify a workable solution. In return, ESA will provide support and advice on its flight-proven ground control software products that will be used by ELSA-d, primarily through the review of mission control design documentation and advice on configuration and system validation and testing.

Conjunction alerts are likely to be supplied a week or so in advance of a mission event and therefore there will be time to finish a mission phase, or to hold off on starting a mission phase until after the conjunction event. Therefore, the servicer and client is planned to always be docked during any Collision Avoidance Manoeuvers (CAMs).

The servicer is designed to include high impulse propulsion so performing a CAM is possible. A proportion of fuel is reserved for potential CAMs during the nominal operational phases and deorbit phases.

For this mission, ESA is responsible for conducting a collision risk analysis using the Assessment of Risk Event Statistics (ARES) software program, a Debris Risk Assessment and Mitigation Analysis (DRAMA) tool. An acceptable collision probability level (ACPL) of 1.0E-4 is used as the threshold for triggering a CAM, which will target a reduction of the ACPL to 1.0E-5 or less and a minimum conjunction separation of 1.0 km. When provided with greater than 1 day's warning, a CAM will be performed to increase the along-track separation. If the conjunction will occur in less than 1 day, a CAM will be performed to increase the radial separation.

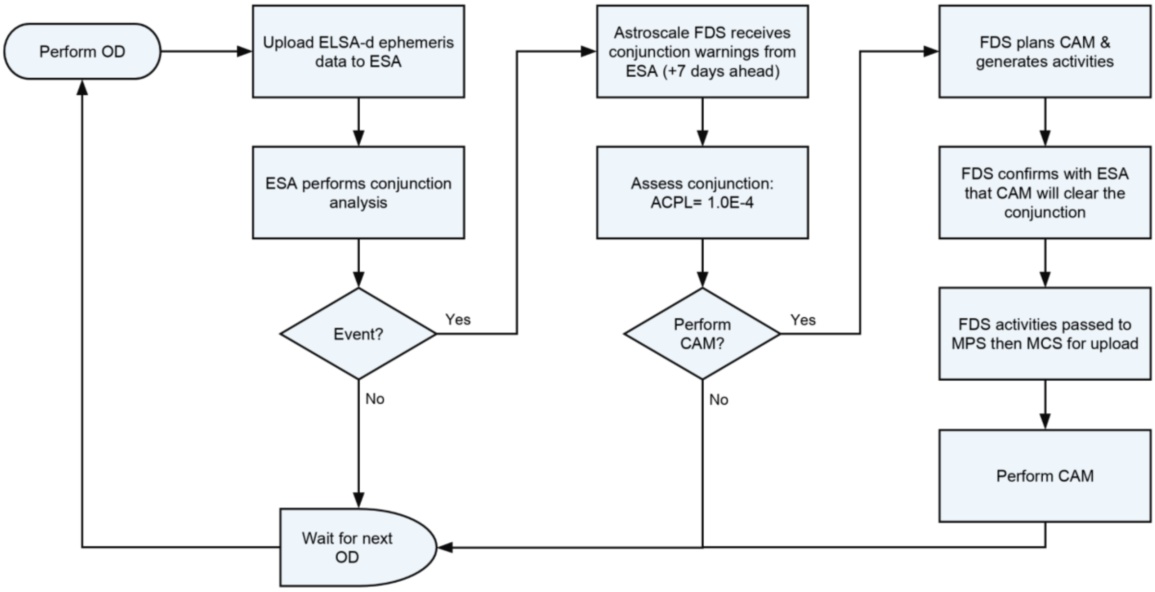

Figure 7: ELSA-d COLA procedure

For objects that are not tracked, there are spacecraft design features that mitigate impacts from debris. Basic design for debris protection is against debris with a diameter 0.2 mm for 11 km/sec. For these micro-debris fragments, the design includes ensuring the tank is inside the vehicle and well shielded from impact. After initial analysis, elements of the harness were open to impact and were thus relocated internally/shielded as required.

The following debris size and countermeasure actions have been analyzed:

- For > 10 cm (visible class/tracked from ground) - Collision Avoidance Manoeuver (CAM)
- For 0.2 mm to 10 cm (invisible class) - Risk allowable (low prob. of impact)
- For < 0.2 mm - Protection and layout designed

ii. Servicer/Client Abort Collision Avoidance

With respect to the servicer and client, passive safe trajectories and safety zones are employed to ensure there is no risk of unintentional collision and approaches are always done safely. In Phase 5, search for the client is done via a walking safety ellipse. The servicer also has the ability to position itself at set distances behind the client, as discussed above. The servicer will often wait at these points for operator go/no-go decisions.

During all experimental rendezvous scenarios, the capability for either a mission interruption or mission abort (passive or active) is available to the servicer. Mission interruption only occurs where the failure is known to be minor. Major failures (or unknown failures) result in full abort. A mission abort puts the servicer into a safe trajectory that is guaranteed through natural motion to be collision-free.

1. **Mission Interruption.** This is a “lesser abort,” and can be either a stop or retreat. It is available for proximity operations where there is a failure that will not result in a collision with the client.
    a. **Stop**: This submode is available only when the servicer is performing “straight-line approach” on the in-track axis or “final approach.” The servicer reduces its relative velocity to 0 m/s and keeps its current position with respect to the client while the fault is diagnosed.
    b. **Retreat**: “Retreat mode” is available only when the servicer is performing “fine position keep” or “stop” during point B acquisition. The servicer retreats from a current position to halt at a target position using a 2-impulse tangential manoeuver.

2. **Passive abort.** This is the simplest and most certain way to avoid a collision. The servicer stops orbit manoeuvering and drifts, which naturally increases its distance from the client.

3. **Active abort.** The servicer performs one or two orbital manoeuvers to increase the distance from client by entering a safety trajectory. In a final approach, the relative distance between servicer and client will be too close to safely apply a passive abort. In such a case, active abort is necessary to guarantee that the servicer and client do not collide.

Aborts will mostly be triggered automatically. However, if the operators notice any servicer or client states or telemetry indicating that the mission is compromised or a collision could occur, the abort will be commanded from the ground.

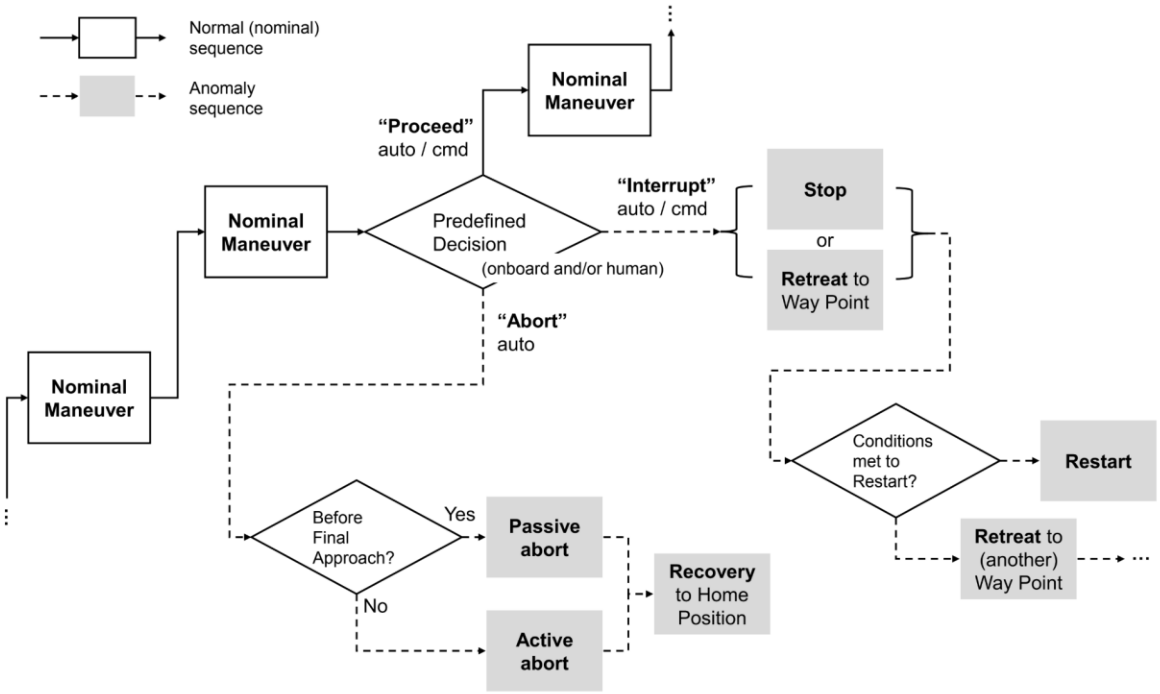

Figure 10: Mission Interruption and Mission Abort Scenarios

5. Deorbit, passivation, and re-entry hazards

ELSA-d will conduct phases 1-5 of the demonstration in the deployment orbit. Phases 5 and 6 are the deorbit and passivation scenarios.

a. End-of-life de-orbit

If there is sufficient remaining fuel, the combined servicer and client will conduct one or more deorbit manoeuvers to lower the perigee. Active operations will be maintained in any case until the servicer's orbit has decayed below that of the International Space Station. The servicer's attitude will be controlled so as to increase its cross-sectional area (to increase drag) while maintaining a sun aspect angle that will generate the required power level.

	Nominal Scenario, Controlled Re-Entry	**Nominal Scenario, Uncontrolled Re-Entry**	**Deployment with immediate failure (max. alt.)**
Orbital Altitude	550 km	550 km	600 km
Maximum De-Orbit Life	7 years	11 years	21 years

Table 2: De-Orbit Lifetimes

As depicted in Table 2 and Figure 12, under nominal conditions with controlled de-orbiting, Astroscale projects a 7-year de-orbit period and an 11-year period with uncontrolled de-orbiting for the combined servicer and client spacecraft. In the case the servicer fails immediately upon deployment, then Astroscale projects a 21-year de-orbit period at maximum height of 600 km.

Nominal starting orbit:

- a = 6928.137 km (altitude = 550 km)
- $e \leq 0.005$
- i = 97.593°
- LTAN = 11:00 +/- 8 min

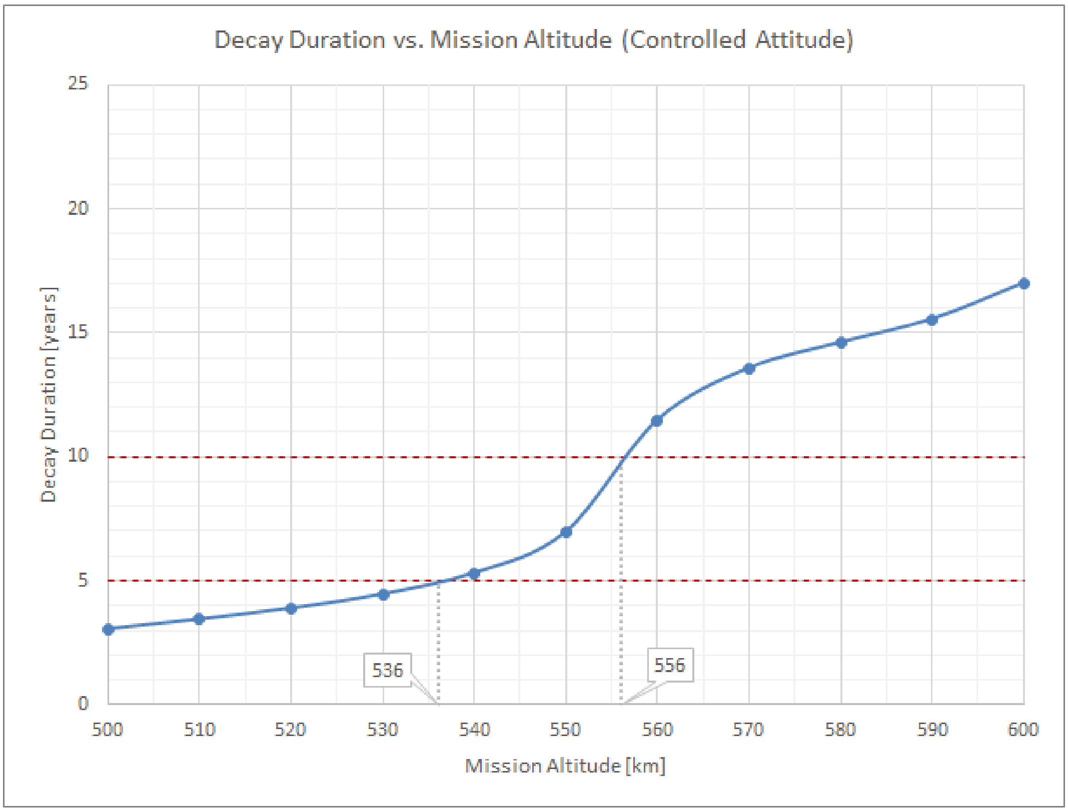

Figure 12: Decay Duration of Combined Servicer and Client

b. Passivation

The closeout phase for the ELSA-d mission is achieved by passivating the space segment. This is performed once the mission and disposal phases have been completed. The sequence overview is as follows:

- Empty the propellant tanks by performing a series of de-orbit manoeuvers:
  - Align spacecraft along negative V-bar direction
  - Fire -X thrusters until complete blowdown achieved
- Disconnect batteries from solar array charge strings
- Fully discharge batteries
- De-spin reaction wheels using magnetorquers
- Connect batteries to dump resistors
- Switch off transmitters

c. Spacecraft Re-entry Hazards

ESA is in the process of conducting a full DRAMA analysis for the servicer and client together as they de-orbit. *See supra* Section 4.b. However, a partial analysis on the titanium tank on the servicer (which is the most likely component to survive re-entry) has already been conducted. The risk of human casualty associated with the re-entry of this component meets the international standard.