An Exploration of Space Situational Awareness (SSA) Needs for Active Debris Removal (ADR) Operators

Jason Forshaw
Astroscale UK
Mike Lindsay†, Charity Weeden[*], John Auburn[⬩], Chris Blackerby†
†Astroscale Holdings, [*]Astroscale US, [⬩]Astroscale UK

ABSTRACT

Comprehensive Space Situational Awareness (SSA) data allows users to accurately interpret and characterize the activity of satellites, improving operational safety and reducing the risk of collisions by increasing ability to recognize abnormal or off-nominal behavior. In the years since its origin, there have been increasing use cases for SSA, such as asset investment protection, insurance claims, and safety of flight. Now with the advent of new Active Debris Removal (ADR) and In-orbit Services (IOS) missions, SSA becomes an important part of operational services.

Astroscale is one of the few companies in the world proposing to aid in the removal of orbital debris through the provision of the following in-orbit services: end-of-life (EOL) targeting the LEO constellations, ADR targeting existing larger space debris, and life-extension targeting GEO satellites. Astroscale is working on a variety of project and future missions in this arena. These include the ELSA-d mission (the world's first commercial demonstration of ADR, launching in 2021), commercial developments under the ESA Sunrise Program with OneWeb to mature technology for future end-of-life missions, and the institutional ADRAS-J mission (JAXA's first mission ADR to observe debris, in light of future removal).

As we grow our business, develop our capabilities, and become closer to fully operational services, Astroscale is developing a clearer understanding of SSA needs for its future ADR missions. This paper aims to address those specialized needs, understanding the key technical drivers.

In addition to the SSA needs discussed above, the paper will provide an overview of each core phase of the concept of operations (CONOPS) and how SSA is needed in each phase of the mission.

This paper overall provides a unique customer-side insight into SSAs needs for ADR. As Astroscale are one of the first users of SSA for this specific application, we are a core player driving the way SSA provision evolves in future to support these missions.

1. INTRODUCTION

Please note: this short technical paper is designed to accompany an AMOS poster of the same name.

Comprehensive Space Situational Awareness (SSA) data allows users to accurately interpret and characterize the activity of satellites, improving operational safety and reducing the risk of collisions by increasing ability to recognize abnormal or off-nominal behavior. In the years since its origin, there have been increasing use cases for SSA, such as asset investment protection, insurance claims, and safety of flight. Now with the advent of new In-orbit Servicing (IOS) missions such as Active Debris Removal (ADR), SSA becomes an important part of operational services.

Astroscale is one of the few companies in the world proposing to aid in the removal of orbital debris through the provision of the following in-orbit services: end-of-life (EOL) targeting the LEO constellations, ADR targeting existing larger space debris, and life-extension targeting GEO satellites. As we grow our business, develop our capabilities, and become closer to fully operational services, Astroscale is developing a clearer understanding of SSA needs for its future ADR missions. This paper aims to address those specialized needs, understanding the key technical drivers.

2. SSA NEEDS FOR ADR

In a classical ADR mission, we have a servicer (the satellite doing the removal) and a client (the asset in space being removed). We will be using this terminology throughout the paper.

We break down our SSA needs into 5 categories:

(1) Pre-launch Assessment

Important data can be provided by SSA even before a servicer is launched, such as client position and, in some cases, client attitude and tumbling rate. ADR services in future will have inherent fixed tumbling rate servicing limits – if a client tumbling rate is too high, then a client may be unserviceable to begin with. Such information needs to be ascertained before a service commences, otherwise this places risk on the ADR provider if they launch a servicer only to find that they can't perform the intended removal.

(2) Search and Approach

SSA is mandatory for future search and approach maneuvers. Generally, the client is defunct and the satellite has failed in a way such that it needs removal. In this case, absolute positioning systems on-board e.g. GPS are not functional and thus the client's position can only be known through use of SSA services. One of the first steps in a servicer rendezvousing with a client is the "search and approach" phase (see CONOPS section below) which thus requires use of an SSA service.

(3) Failure Analysis

SSA services can provide some form of failure analysis capability to analyze the conditions surrounding the failure of the client. For example, if the client is tumbling in a specific way, or has unusual trajectory motion, this might indicate a GNC or propulsion failure. Understanding such information before rendezvous, could be very valuable to the ADR service provider.

(4) Collision Analysis and CAM Alerts

CAM (Collision Avoidance Maneuver) alerts are a core stable of conventional SSA provision and are also needed in ADR missions. The servicer must be able to move out of the way of other satellites, or trackable debris. However, depending on the accuracy of the SSA data, SSA providers may be able to provide independent tracking to help prevent collisions during Rendezvous and Proximity Operations (RPO).

(5) Independent Monitoring for Ensuring Transparency

Finally, regarding safety and security, SSA can provide independent monitoring for ensuring transparency for any regulatory and potential insurance compliance. In particular, tracking of the servicer during the course of the mission can provide confidence that no malicious behavior is being undertaken.

It is to be noted that the needs for SSA for ADR do differ than the broader needs of SSA for mass observation of satellites. In a conventional SSA scenario (e.g. government operational intelligence, general tracking of debris), SSA providers scan for, or track, a very large database of objects. SSA for ADR differs in that, specifically for Needs #1 to #3, ADR customers are looking for specific tracking of just 2 entities – the servicer and the client. Thus, high quality data on 2 objects is far more valuable than low quality data on a very large number of objects.

SSA data enters an ADR provider's ground segment and it can then be used for ADR mission purposes. Please note that the necessity to have SSA for at least Need #2 means an SSA provider is part of an ADR mission supply chain. Also note that not all the SSA data required needs to come from the same provider.

The following SSA data factors need to be considered as part of SSA provision for ADR:

- Data Accuracy – This is a function based on number of observations, modeling, and type of algorithm used. The SSA data accuracy should be sufficient to suit new orbital activities such as RPO. Present state of the art accuracies are: 0.1 arc seconds (optical)/ VM +20 and <100 m (radar).

- Data Sensitivity – It is imperative that the satellite can be resolved. Present capabilities include roughly 2.5X10X10 cm+ in LEO; 10 cm - 1m in GEO, so generally this is not an issue, but this is a factor in the SSA processing algorithm.

- Data Frequency and Timeliness – It is important that SSA data is delivered to an ADR ground segment with minimal lag and at the frequency required for search and approach and RPO phases as appropriate.

- Data Availability and Coverage – it is imperative that data is available at the requisite times in the mission phases (see CONOPS section below), but especially in the search and approach phase. This means that the incoming data must be in alignment with the necessary passes required to undertake the CONOPS. This is a major consideration, since ADR missions may require chaining of multiple ground stations in order to perform a full RPO sequence and data must be available during those periods.

    - Many SSA providers may only provide data at specific times, or data could be interrupted by cloud cover for optical systems. If cloud cover is an issue, the SSA provider should have multiple systems such that there is continuity in the data even if there are cloud obstructions.

3. CONOPS SEGMENTS REQUIRING SSA

Fig. 1 shows a generic IOS mission CONOPS provided by CONFERS, the Consortium for Execution of Rendezvous and Servicing Operations, one of the largest industry-led initiatives into IOS. The ADR path is demonstrated by taking the CONOPS up to capture, then following the "Disposal OPS" path.

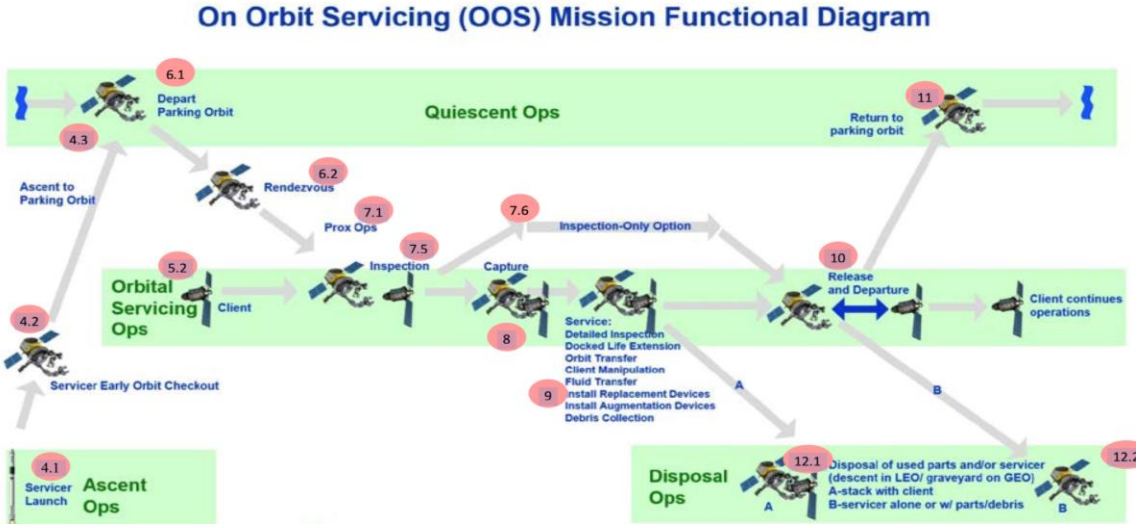

Fig 1. General Mission Phase Classification of In-orbit Service Missions by CONFERS
†Please note: in some IOS cases, the servicer may remain docked to the client after capture.

As the servicer finds and undertakes rendezvous with the client ("search and approach" corresponds to roughly between 6.1, 6.2 and 7.1 in Fig 1), SSA data is needed for the absolute navigation segments. This can range from hundreds of kilometers relative distance between the servicer and client to just a few kilometers. At closer ranges, e.g. less than a few kilometers, or several hundred meters, the servicer can perform a handover to relative navigation

using relative RPO sensors. However, such relative data can also be augmented (fused) with absolute data, if available and of sufficient accuracy to be useful.

Regarding other segments in the CONOPS, Need # 1 is necessary before launch (shown as 4.1 in Fig 1). Need # 3, failure analysis might happen anywhere between launch (4.1) and capture (8), but is most likely in the inspection phase of the mission pre-capture. Finally, collision avoidance, CAMs and transparency (Needs #4 and 5) are required throughout the mission.

4. SSA NEEDS FOR IOS MISSIONS

SSA is a necessary part of all future IOS missions and provides a breadth of value to different users at varying stages of the IOS mission. The table below lays out roughly what SSA needs are for different IOS applications. As can be seen, generally speaking, SSA needs for IOS missions are far less than for ADR missions.

* Cooperative Client (Client position and attitude are known from communication with the Client's sensors)

Table 1. SSA Needs for IOS Missions

SSA Need	**Application**			
	Inspection	Refuelling Reposition*	Repairing Upgrading*	ADR
Pre-launch assessment				✓
Search and approach	✓ (possibly)			✓
Failure analysis				✓
Collision analysis and CAM alerts		✓	✓	✓
Safety and security	✓	✓	✓	✓

5. ASTROSCALE MISSIONS WITH SSA NEEDS

ELSA-d

ELSA-d (End of Life Service Demonstrator), Astroscale's upcoming demonstration mission scheduled to launch in 2021, consists of two spacecraft, a Servicer (~184 kg) and a representative client (~20 kg), launched together in a configuration with the servicer attached to the client. The mission will demonstrate key capabilities and technologies critical to future missions, including navigation, rendezvous, multiple captures (dockings) with the client when tumbling and not tumbling, and de-orbiting of the client and servicer whilst docked together. Although both the servicer and client have GPS, as part of this mission, Astroscale is engaging SSA suppliers to understand their capabilities in SSA in light of future missions.

ADRAS-J

In February 2020, Astroscale announced its selection as the commercial partner for Phase I of JAXA's first debris removal project. The JAXA Commercial Removal of Debris Demonstration project (CRD2) consists of two mission phases to achieve one of the world's first debris removal missions of a large object, the first phase of which has been awarded to Astroscale. This first phase will be demonstrated by the end of the Japan Fiscal Year 2022 and will focus on data acquisition on an upper stage Japanese rocket body. Presently Astroscale is in early discussions with SSA providers for this mission.

Sunrise OneWeb (Phase 1)

Astroscale has been working towards the design of an ADR servicer on Project Sunrise with ESA and OneWeb, which builds on heritage technology from ELSA-d and is equipped with rendezvous guidance, navigation, and control (GNC) technologies and a magnetic docking mechanism, specifically designed to be compatible with docking plates on future commercial satellites. The servicer has been designed with a multi-client ADR capability to remove multiple clients with a single servicer.

GEO LEX Services

Astroscale US, opened in 2019, will presently focus on GEO life extension (LEX) services. Astroscale US announced on 3rd June 2020 it had conducted an asset purchase of intellectual property of the satellite-servicing company Effective Space Solutions (ESS), established Astroscale Israel and hired ESS staff to continue development of life extension technologies to service GEO platforms.

Supply Chain to Support SSA

As Astroscale are one of the first users of SSA for ADR, we are a core player driving the way SSA provision evolves in future to support these missions. It is important that going forward a supply chain is developed globally which can support such missions, given the specialized needs addressed above.

Astroscale have been in discussion with an array of leading SSA providers about future services, some of which propose using ELSA-d as an initial demonstration of their services. Furthermore, Astroscale are involved in SSA policy and studies in the Japan, UK and US. We have developed reports for the UKSA, METI (Japan), CAO (Japan) in this domain, and are presently part of 2 consortiums, through UKSA funding, to investigate aspects of low cost SSA service provision.

6. CONCLUSIONS

This paper has examined the SSA needs of ADR providers and also looked briefly at SSA needs for IOS, the influence on SSA needs on CONOPS and introduced various future Astroscale services that will require SSA data.

Comprehensive Space Situational Awareness (SSA) data allows users to accurately interpret and characterize the activity of satellites, improving operational safety and reducing the risk of collisions by increasing ability to recognize abnormal or off-nominal behavior. Now with the advent of new ADR and IOS missions, SSA becomes an important part of operational services.

This paper overall provides a unique customer-side insight into SSAs needs for ADR. As Astroscale are one of the first users of SSA for this specific application, we are a core player driving the way SSA provision evolves in future to support these missions.