75th International Astronautical Congress (IAC), Milan, Italy, 14-18 October 2024.

IAC-24,A6,6,9,x87881

Ultra-close RPO on-orbit demonstration of ADRAS-J Program

Eijiro Atarashi, Hisashi Inoue (Astroscale Japan Inc.), Gene Fujii (Astroscale Holdings Inc.)

Abstract

Over 60 years of space exploration have led to serious space environmental problems. Upper stages of rockets and decommissioned satellites remain on orbit, contributing to the growing amount of space debris and increasing the risk of explosions and collisions. The Kessler Syndrome, first suggested several decades ago, describes a scenario where collisions between debris generate a cascading effect, leading to even more debris. This risk is no longer theoretical, as collisions with debris have already occurred, leaving the space environment in an unpredictable state.

For debris removal to become a regular activity, strong governmental support is essential for advancing technical development and establishing stable service provision. This requires funding for missions to develop the necessary technology and active policy reforms that will lead to safe and sustainable operations.

In March 2020, JAXA announced it would fund the first phase of a mission focused on the observation, characterization, and eventual removal of a large piece of Japanese space debris. The initial phase of the mission includes the location, close approach, and rendezvous with a Japanese upper stage rocket body, followed by the acquisition of in-situ data to better understand the movement and other characteristics of the debris.

JAXA selected Astroscale Japan Inc. and its ADRAS-J (Active Debris Removal by Astroscale-Japan) program as the commercial partner for the first phase of this mission. This paper explains the critical technologies, the concept of operations, and the results of the on-orbit demonstration of the ADRAS-J program. Launched in February 2024, ADRAS-J has resulted in the world's first unprepared large debris observation mission, demonstrating full-range RPO(Rendezvous and Proximity Operation) to the debris.

Key Words: Space Debris, ADR, ADRAS-J, CRD2, On-orbit Servicing

1. Objectives and Background

More than 60 years of space development have resulted in increasingly serious space environmental problems. Upper stages of rockets and decommissioned satellites remain in orbit, contributing to the accumulation of space debris caused by explosions and collisions. The Kessler Syndrome, in which debris from collisions triggers a cascade of further collisions, was predicted decades ago and is in its infancy, leading to an unpredictable space environment.

International organizations such as the United Nations Committee on the Peaceful Uses of Outer Space and the Inter-Agency Space Debris Coordination Committee took the initiative in implementing guidelines for debris reduction to prevent further debris generation. Japan has made significant contributions to these international efforts. However, directly improving the space environment is challenging due to the growing number of spacefaring nations, increased private sector activity, and insufficient restrictions on debris generation, resulting in further debris. Recently, the rise of satellite constellations has brought global attention to the space debris issue and environmental sustainability in space. There is now a general consensus that large debris must be removed before it is further fragmented by explosions or collisions.

Astroscale is a provider of on-orbit servicing services and solutions, including active debris removal (ADR), with a vision for the sustainable development of space. ELSA-d (End-of-Life Services by Astroscale-demonstration) was the world's first commercial debris removal demonstration mission in low Earth orbit, aimed at paving the way for future commercial EOL (End-of-Life). Astroscale Japan Inc. and its ADRAS-J project, which utilizes the technologies and knowledge gained from the ELSA-d mission, was selected as the private sector partner for Phase I of the world's first commercial debris removal technology demonstration (CRD2: Commercial Removal of Debris Demonstration), implemented by JAXA. In Phase I, the ADRAS-J mission involves a proximity approach and operations to an unprepared debris client to capture images and assess the state of the debris, including its movement, damage, and deterioration after prolonged exposure in orbit. In addition to these JAXA mission requirements, the ADRAS-J mission will also demonstrate Astroscale's own technical objectives. The knowledge and data obtained in Phase I will contribute to Phase II [1,3] , for which Astroscale Japan Inc. signed a contract as the private sector partner in August 2024 (scheduled to launch in 2026 or later), with the aim of capturing and removing the unprepared debris client.

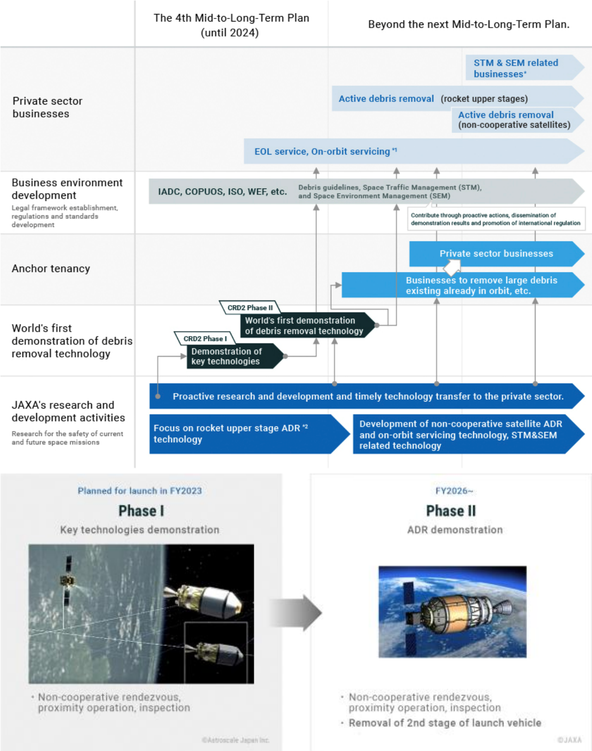

Fig. 1: CRD2 program (from JAXA website) [1]

2. Approaches to the Space Environment

The analysis of the removal of existing debris was presented in June 2019 by Holger Krag, Head of the Space Debris Office, ESA, and details conditions required to improve the space environment (Figure 2)[4]. According to this analysis, the following three achievements are required to improve the space environment (pink line).

(a) 100% Passivation

(b) 90% Post Mission Disposal (PMD)

(c) ADR of five high-risk large debris objects per year for the next 200 years

However, the situation is expected to deteriorate until around 2070. To accelerate the improvement of the space environment, it is necessary to increase the PMD rate (e.g. 99%) and the number of ADR. In reality, the PMD rate has not yet reached 90% [5], and achieving (a) and (b) is proving difficult.

Therefore, ADR is also essential to meet the conditions of (a) and (b), especially for spacecraft that have not been passivated or disposed of according to the PMD rate. In other words, the measure of "removing debris" is necessary for all three conditions (a), (b), and (c) for improving the space environment.

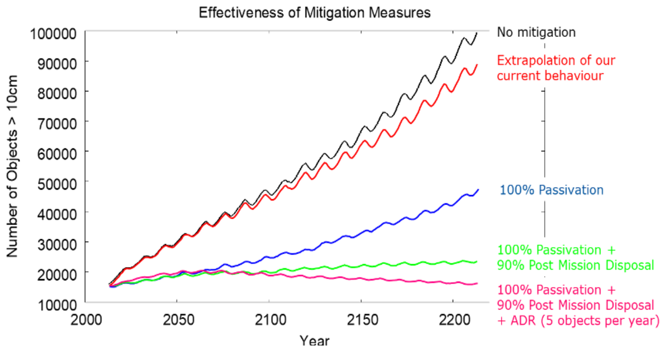

Fig. 2: Effective of Debris Reduction Measures [4]

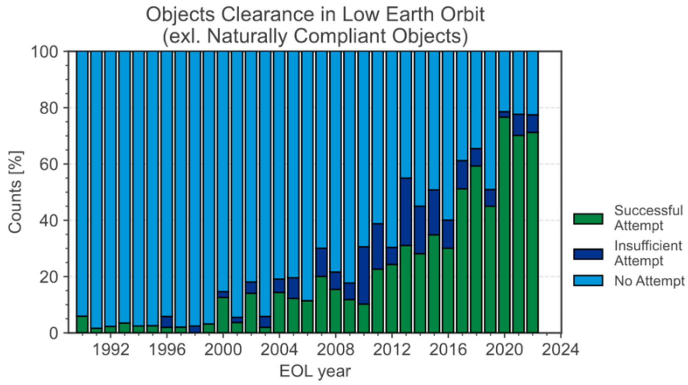

Fig. 3: PMD compliance rate with low orbit [5]

3. ADRAS-J Project Overview

The ADRAS-J project was selected as the contractor for Phase I of JAXA's CRD2 (Commercial Removal Debris Demonstration) program with the contract finalized in March 2020 (Fig. 1, from JAXA website) [1]. A schematic diagram of the mission is shown in Fig.4. The mission includes both JAXA's objectives and Astroscale's technology demonstration objectives. In the JAXA mission, the ADRAS-J Servicer will approach within 50 m of an unprepared debris object and conduct fixed-point and fly-around observations. In the Astroscale mission, the satellite will conduct an ultra-close approach experiment as a precursor for future capture missions.

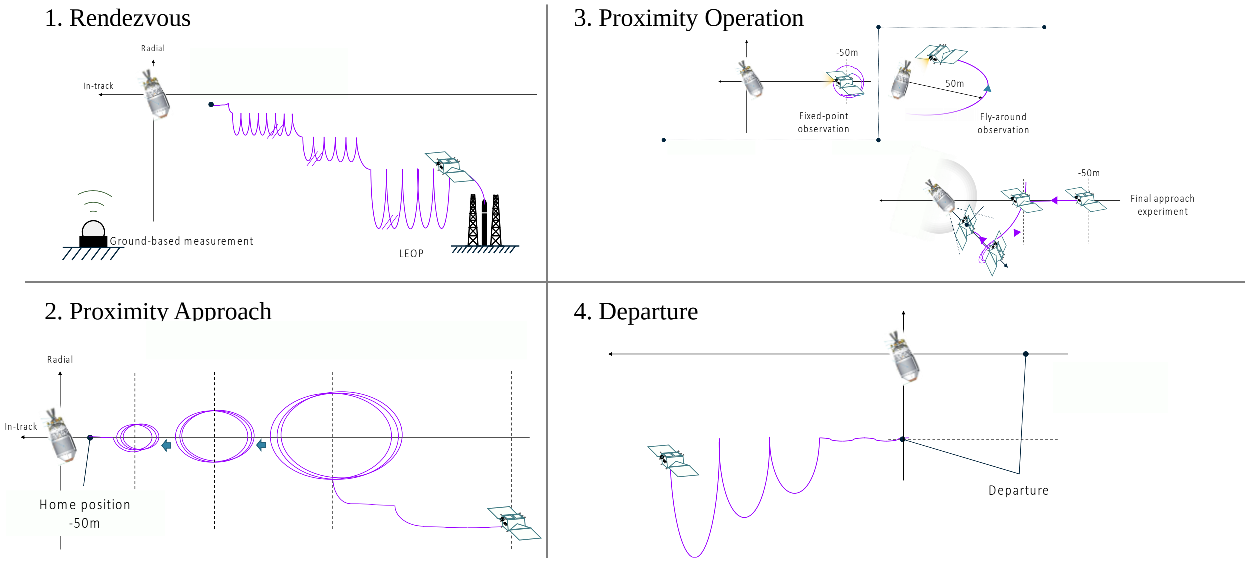

Fig. 4: Outline of ADRAS-J mission

The mission phases are as follows:

Initial operation (LEOP) and commissioning: Servicer is launched into orbit, and initial checks are performed. The initial orbit is determined by ground observations.

Rendezvous: Servicer on-orbit maneuvers into position behind the Client by aligning its phase, eccentricity, and orbital plane.

Proximity Approach: Servicer switches to relative-navigation using onboard payload sensors and approaches the Client.

Proximity Operation: Servicer performs fixed-point and fly-around observations, capturing image data of the Client. Both JAXA and Astroscale's objectives are met during this phase.

Departure: Servicer performs on-orbit maneuvers, moving to a safe distance from the client.

Fig. 5 shows the ADRAS-J Servicer, which demonstrates the ADRAS-J mission on orbit. The Servicer is approximately 3,700mm x 800mm x 1,200mm (solar array deployed) and weighs approximately 150kg (wet). The target as the Client is the upper stage of the H-IIA rocket that launched GOSAT in 2009 (approximately 11 m long, 4 m in diameter, and 3 ton in mass).

The technical features of the ADRAS-J mission are briefly explained. As mentioned above, the ADRAS-J mission is a mission that demonstrates rendezvous and proximity operations from long distance to very close distance for unprepared object. Therefore, technologies that can cover all ranges are essential. In order to achieve RPO (Rendezvous and Proximity Operation) technology that covers all ranges, navigation methods that are considered optimal for each distance range are applied.

Long-range (several thousand to several hundred kilometers): Absolute navigation using ground observation data from SSA providers and GPS data from the Servicer satellite

Medium-range (several hundred to several kilometers): Relative navigation using Angle Only Navigation (AON) with a visible camera (VISCam), which is one of the relative navigation sensors installed on the Servicer

Fig. 5: Outside view of ADRAS-J Servicer

Short range (several kilometers to 50 meters): Relative navigation using Model Matching Navigation (MMN) with an infrared camera (IRCam), which is one of the relative navigation sensors

Very short range (50 meters to several meters): Relative navigation using Model Matching Navigation (MMN) with a LiDAR, which is one of the relative navigation sensors

The relative navigation sensors installed on the Servicer are not only products developed for space use, but also include so-called COTS sensors developed for ground use. The objective to adopt COTS sensors is to shorten development period and reduce costs, and various tests have been conducted on these COTS sensors to confirm that they can achieve sufficient performance and durability in space.

4. Mission Status of ADRAS-J Project

Astroscale Japan Inc. signed the contract for CRD2 Phase I in March 2020 and started the project. Annual milestones (MS) were defined in the contract, with MS1 (Preliminary Design Review), MS2 (Critical Design Review), and MS3 (Pre-Shipment Review) completed. Each review focused on safety design and confirmed that the mission design was safe and sufficient.

The Servicer was shipped in October 2023 and launched on February 18, 2024, from Rocket Lab's Launch Complex 1 in New Zealand aboard an Electron rocket. Fig. 6 shows the satellite's separation from the launch vehicle.

Fig. 6 : ADRAS-J Servicer separated from the rocket

After the launch and orbit injection, communication with the Servicer was established during the first ground station pass, and LEOP was carried out over the next few days.

After completing LEOP, the Client's orbital position was calculated using the Space Situational Awareness (SSA) service, and rendezvous operations to approach the Client from the launch vehicle injection orbit began on February 22, 2024. During the rendezvous phase, the optimal approach trajectory plan was constantly updated, taking into account the amount of fuel consumed and the mission period, based on the GPS data from the Servicer and the SSA data for the Client. By completing all operations in-house, a reliable and safe rendezvous phase was achieved.

After the rendezvous phase, the proximity approach phase began on April 9, 2024. The SSA data used in the rendezvous phase can obtain information without any constraints on the relative position relationship between the Client and the Servicer, however, the orbit determination accuracy is insufficient for Rendezvous and Proximity Operations (RPO). Therefore, it is necessary to estimate the relative orbit with the Client and approach it safely using multiple onboard payload sensors that can observe the Client.

When the relative distance range is several hundred kilometers or more, Angles-Only Navigation (AON)[10] using the Servicer's visible camera was used. This AON method is effective for observing objects in orbit as points. In order to satisfy the orbit determination accuracy required for RPO using AON, it is necessary to continuously update both the current orbit estimation and future orbit plan. All the image processing functions and orbit estimation software required for AON were developed by Astroscale and were fully integrated with the orbit planning tools and operational procedures to achieve flexible and immediate assessments and operational decisions.

Fig. 7 : Client image at AON

On April 16, 2024, when the relative distance was reduced by AON and the satellite reached a range where it could observe the client with some resolution rather than a point with the payload sensor, the satellite's navigation was switched to on-board relative navigation.

Fig. 8 : Client image prior to IRCam handover

During the on-board relative navigation phase, it is possible to estimate the relative orbit between the Servicer and Client without using the ground system. However, ensuring the safety of relative navigation is challenging without data analysis on the ground to observe the Client and prevent collisions. Therefore, the ADRAS-J mission utilizes a method called Model Matching Navigation (MMN) [10]. This navigation method estimates the relative orbit by comparing observations of the Client made by the payload sensor with the Client's model data. The on-board image processing functions and relative orbit determination software required for MMN are developed by Astroscale, and the Model Matching algorithm is based on the on-orbit data. The parameters used in the Model Matching algorithm can be flexibly changed based on the orbital data. The in-house development of all the necessary functions for MMN has contributed greatly to the servicer's reliable approach to space debris that cannot be observed from the ground.

Fig. 9 : IRCam client images

In operations where frequent dV (delta-V) maneuvers are performed to control the relative position of two objects that are in close proximity, the Servicer's current relative state quantities are expressed in the RIC coordinate system (R: radial, I: in-track, C: cross-track) with the Client as the origin. In such operations, understanding the relative trajectory over a relatively long span is more important than knowing the precise relative position at each moment. The control target is not set to aim for a position at a certain time, but rather to consider what kind of relative trajectory is preferable. In such cases, the relative orbital element (ROE) is very useful. Using the product of the ROE and the mean orbital radius of the central body, the relative geometric relationship between two bodies can be expressed as follows.

$a_0 da$ … *Difference in the mean orbital radius of the relative orbit to the central object*

$a_0 d\lambda$ … *Offset in the along track direction of the relative orbit to the central object*

$a_0 de$ … *Amplitude in the radial direction of the relative orbit to the central object*

$a_0 di$ … *Amplitude in the crosstrack direction of the relative orbit to the central object*

The geometric relationship between these parameters and the relative orbit of the Servicer in the client-centric RIC coordinate system is shown in the schematic diagram of Fig 10. Note that the Servicer's trajectory, indicated by blue in the figure, is closed, but strictly speaking, the Servicer's trajectory drifts in the in-track direction when there is an offset to $a_0 da$.[11] By setting the ROE appropriately, the Servicer can pass through a trajectory that does not contact the Client's trajectory while keeping the relative distance to the Client close. This trajectory is called a Safety Ellipse (SE) because it appears to be an elliptical spiral trajectory from the Client's point of view.[12]

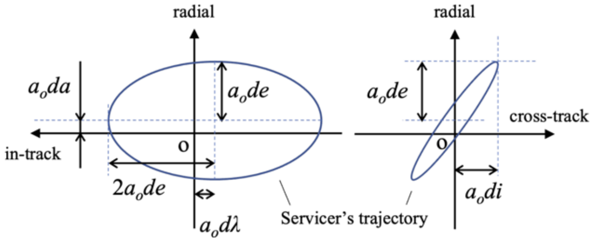

Fig. 10 : Schematic diagram of geometric relationship between relative orbit of Servicer and ROE in 4 Client center RIC coordinate system

After safely approaching the SE by changing its trajectory geometry, the Servicer moved to the forced motion phase to maintain a more accurate relative distance to the Client. In this phase, the Servicer performs a continuous dV maneuver to maintain the relative relationship and observe the Client in a closer proximity and under steady-state conditions. Since it is necessary to enter a relative orbit that is different from the SE, there is a risk of collision with the Client and the creation of new debris if an anomaly occurs after this phase. To mitigate this risk, ADARS-J is equipped with an on-board FDIR (Fault Detection, Isolation, and Recovery) system, which can perform an abort maneuver to avoid collision if the Servicer detects an anomaly and the distance to the Client is within a critical range. This function enables the mission to approach space debris objects—with unknown characteristics that have never been directly observed before—while ensuring safety in orbit despite the high risk of collision.

After completing the proximity approach phase, the ADRAS-J mission reached a relative distance of 50 meters for the first time on May 23, 2024, and began the proximity operation phase. The JAXA mission requires two types of observations: fixed-point and fly-around observation. The fixed-point observation maintains a relative distance of 50 m and takes images of the Client with the visible camera for one orbit. This was the first mission globally to safely approach actual debris and conduct a short-range survey of its condition (based on our own research as of May 2024). The mission confirmed the condition and changes of the Client's surface components that has existed in space for a long period of time. In addition, this observation can characterize the Client’s rotation rates and attitude disturbances. The information obtained from this mission will not only improve the certainty of the capture of the Client during future operations but also offers valuable insights into the degradation status of debris currently in orbit. Three fixed-point observation missions were conducted on June 17, 2024, and July 14, 2024, achieving long-term observation of the Client's condition.

Fig. 11: Client image from 50m behind

The fly-around observation involves capturing images of the Client using the visible camera while maintaining a relative distance of 50 m and flying around the Client. While fixed-point observation can only obtain data from one direction because the relative position is fixed, fly-around observation can observe the Client from multiple directions, providing a more comprehensive dataset. The ADRAS-J mission attempted its first fly-around observation on June 19, 2024. During this attempt, the Servicer orbited around the Client for about one-third of a revolution and succeeded in capturing images of the Payload Attach Fitting(PAF), assumed to be a candidate for the Client's capture.

Following this, an anomaly in the relative attitude control system with the Client was detected, and the Servicer safely retreated without collision due to the FDIR system. Since there are inherent uncertainties when approaching space debris, the assumption of unexpected events during proximity operations must be considered. In this instance, ADRAS-J demonstrated the successful operation of its onboard FDIR system, safely aborting as designed and proving that the design necessary to perform on-orbit services were in place.

Appropriate changes were made based on the data obtained from the first fly-around attempt. The second attempt was successfully completed on July 15, 2024, followed by the 3rd fly-round observation on July 16, 2024. The fourth fly-around observation was executed in a different orbital plane than the previous two, and was also successfully completed in August 2024. A controlled fly-around at a 50 m relative distance from space debris in orbit is an unprecedented operation.

With the completion of the JAXA mission, Astroscale’s mission will follow, leading to the safe departure from the Client and deorbit operations.

Fig.12: Client image captured by the fly-around observation #1

Fig.13: Client image captured by the fly-around observation #2

5. Uniqueness in ADRAS-J Operations

As mentioned above, the ADRAS-J mission changed its operation methods significantly depending on the relative distance to the Client. Particularly after the proximity approach phase, the frequency of configuration changes and orbit/trajectory change dV maneuvers associated with changes in navigation according to the relative distance from the Client increased. This led to a surge in tasks that had to be managed simultaneously. To accommodate these demands, a large number of ground station passes were secured (11 ground stations were used, and approximately 50 passes within a 24 hour period during critical phases). In addition, the status of the Servicer's autonomous relative attitude and relative orbit control was regularly monitored to ensure a safe and reliable demonstration of these technologies.

At close range to the Client, precise control over relative distance was essential. However, factors like differential drag

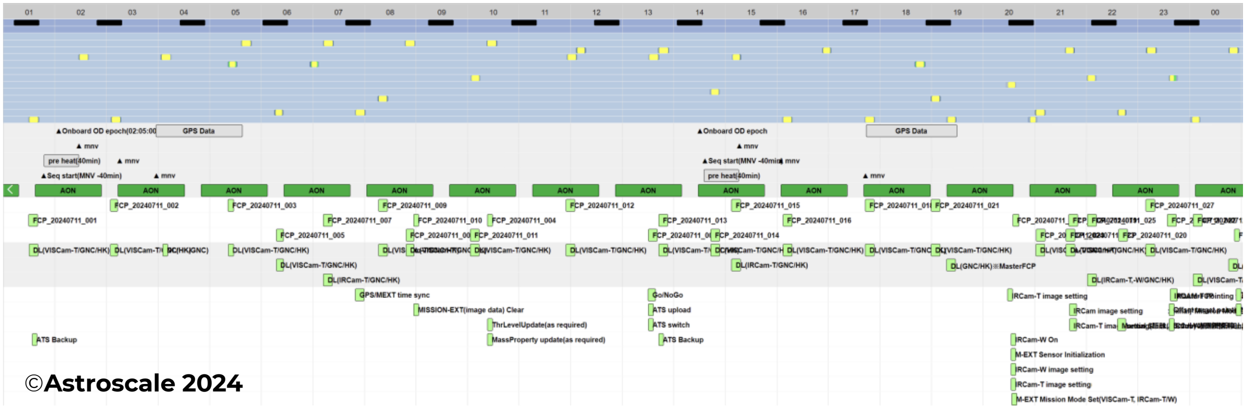

Fig.14 : Daily operational timeline (proximity approach)

estimation errors, dV maneuver control errors, and other factors caused deviations from the plan. This required many updates to both trajectory plans and maneuver timings, which in turn affected the schedule for the following day. As a result, mid-term adjustments to the overall plan were necessary, and modifications to the ground station pass schedule and operational timeline were frequently made while considering various constraints. The operations had to be changed flexibly according to the satellite's status, relative distance to the Client, and positional relationship with the sun, etc. Therefore, multiple contingency plans were developed and procedures were changed in a timely manner to ensure smooth operations.

Examples of operations with time constraints include the AON relative navigation phases and the AON relative orbit control. AON has an observability problem, which greatly affects navigation accuracy and orbit injection accuracy, but the orbit was transitioned at pre-determined intervals to solve these problems. The time spent in each orbit was limited to approximately 12 hours, and the limited pass was used to acquire the necessary data for AON from Servicer, including GPS, Servicer attitude, Client image data from the Servicer's visible camera, and the orbits of the Servicer and Client on the ground side. The ground side requires complex tasks such as orbit determination, dV maneuver planning, execution of orbit change dV maneuvers based on instructions from the ground, and plan updating based on execution results. Ground-based tasks require multiple teams to exchange and process data, so smooth coordination is essential. When the operation team was first formed, it faced challenges in completing all processes in a timely manner. However, through pre-launch training and process improvements, the team improved its skills and acquired the technical expertise to execute the tasks without fail.

In addition, certain missions, especially in proximity operations, require long periods of continuous passes to make go/no-go decisions at the start of critical missions or for collision safety monitoring. Each pass is only about 10 minutes at most, so if more time is needed for command transmission opportunities or satellite status monitoring, continuous passes were secured by switching between ground stations. When switching between ground stations, manual carrier-up and carrier-down operations by the ground station

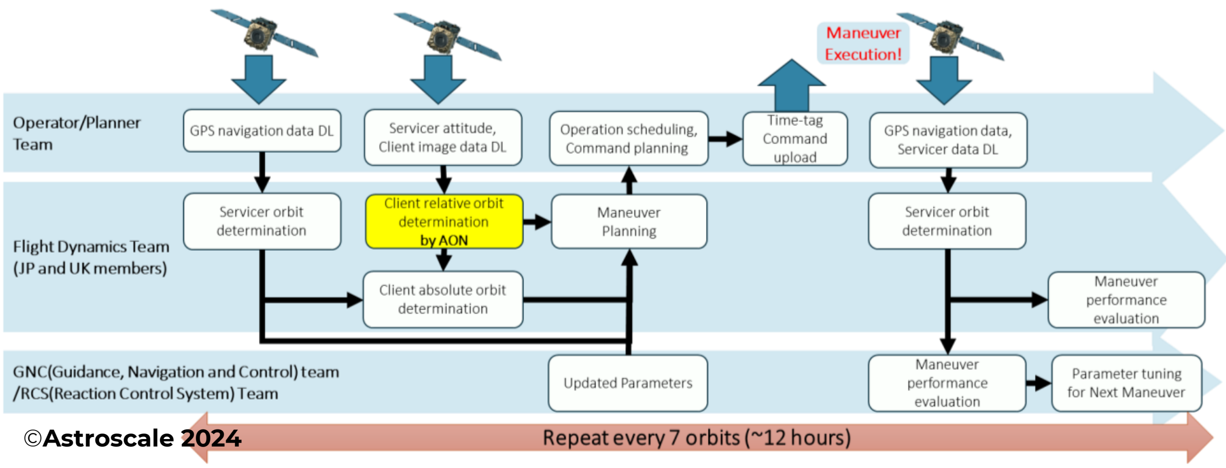

Fig. 15 : Example of dV maneuver implementation flow

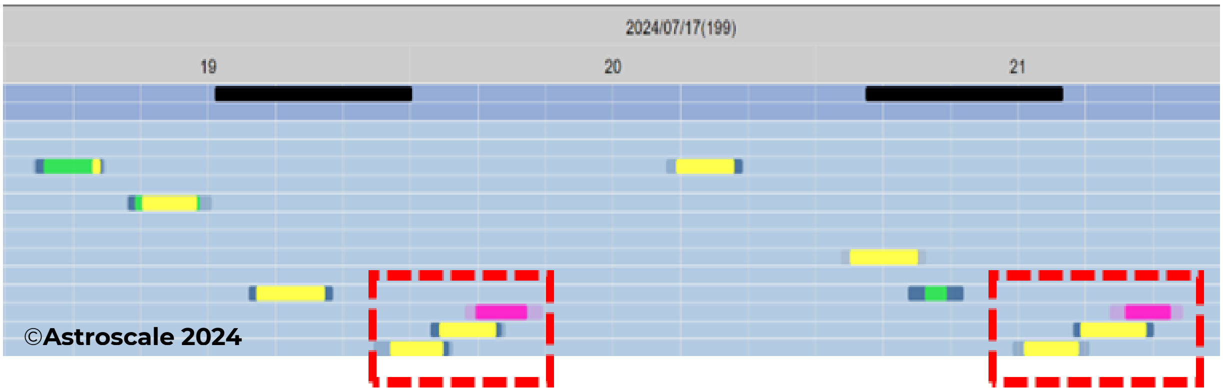

Fig. 16 : Example of ground station continuous visibility (Proximity operation)

operators are required, so smooth coordination with each ground station is necessary. Before the actual day of use, rehearsals were repeatedly conducted with ground stations to establish a solid switching method that takes into account the characteristics of each ground station.

The ADRAS-J operations are conducted in the MCCs (Mission Control Center) at Astroscale in Japan and the UK, and the operation team consists of members from Astroscale Japan and Astroscale UK. The team is in close coordination with the UK MCC through constant audio and video connections and individual communication tools. The team has established an efficient 24-hour operation system, with UK members in charge of nighttime operations in Japan.

Fig. 17: Mission Control Center (Japan)

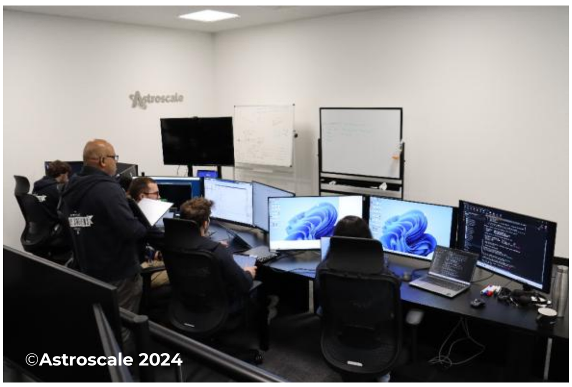

Fig. 18 : Mission Control Center (UK)

6. ADRAS-J Safety Design

Ensuring mission safety is one of the most important requirements for the ADRAS-J mission. The mission adheres to JAXA's standards JERG-2-026 "Safety Standard for On-Orbit Servicing Missions" and JMR-003 "JAXA Space Debris Mitigation Standard". In addition, the ADRAS-J mission obtained permission based on "Guidelines on a License to Operate a Spacecraft Performing On-Orbit Servicing" established by the Cabinet Office of Japan.

The safety design of the ADRAS-J mission, which was performed in-house by Astroscale, has three major factors.

The first is safety for the Client. It is necessary to approach the Client without collision. In the rendezvous phase (far range), a passive safety orbit design was applied to guarantee an orbit that would not cause collision with the Client even in the event of a single failure. In the proximity approach phase, a safety ellipse (SE) trajectory (see Chapter 2) was applied to design a trajectory that would not cause collision with the Client even in the event of a single failure (passive safety trajectory). In the proximity approach and proximity operation phases, the satellite departed from the approach trajectory to the Client by using active abort, which actively fires the thrusters. The passive abort and active abort are basically implemented as part of the onboard FDIR, and the logic was verified using a software simulator and hardware simulator, and the robustness to parameter variation was evaluated and verified using Monte Carlo simulations.

The second point is collisions with objects other than the Client. Since ADRAS-J's mission was carried out in the Client's orbit, there were also relatively many other objects flying in that orbit. To mitigate this, collaboration with several SSA providers, launchers, and other satellite operators was essential to perform collision analysis of launch trajectories and trajectories before and after each dV maneuver. Since the dV maneuver frequency was high and the intervals were short, several safety evaluations of the dV maneuver were conducted at once.

The third point is the safety of the Servicer. Balancing mission success with the Servicer's safety was paramount. Safety is guaranteed through the design of FDIR, which took a layered approach with failure detection at the component, subsystem, and system levels. Early-stage detection allowed the mission to continue as much as possible, while system-level FDIR could trigger passive or active aborts.

In addition, a deorbit plan is in place to ensure the Servicer reenters Earth's atmosphere within five years after the mission, minimizing its time in orbit.

7. ADRAS-J Abort and Recovery Operations

The validity of the above safety design was proved during the first attempt of the fly-around observation. When the Servicer was about one third through the revolution, the FDIR for the anomaly in the relative attitude control system was activated and an active abort was executed. At this time, the Servicer was injected into a trajectory, moving away from the Client as designed.

In parallel, while confirming the Servicer's trajectory, the satellite's condition was also recovered. In addition to recovering it to the normal attitude mode (LVLH), turning on/off of components was performed and parameters were changed, etc. Although the recovery operation procedures were prepared in advance, the procedure was further optimized in actual operation, and the procedure was verified and implemented as necessary.

After the safety of the trajectory was confirmed using the GPS data from the Servicer and the data from the SSA provider, a recovery plan was developed. Normally, the approach from behind the Client is a baseline, but the approach from the front of the Client using SE was attempted after the abort.

As a result, the knowledge gained from the previous approach was utilized, and the approach duration was significantly reduced.

8. Conclusion

The ADRAS-J project, launched by Rocket Lab on February 18, 2024, successfully demonstrated key technologies required for RPO with unprepared objects. This includes adjusting the launch trajectory with the launcher[13], approaching using absolute navigation at far range, relative navigation via the ground system at medium range, and relative approach using onboard navigation at close range. During the mission, the output of various sensors was verified, and the safe approach within 50m was achieved, along with fixed point observations and fly-around observations, successfully completing the JAXA mission. In addition, since safety was a major concern, the mission also verified the FDIR system, as well as active abort capabilities, which are both crucial for safe operations.

Looking forward, the next phase of the mission will involve the execution of the Astroscale mission, followed by ADRAS-J's deorbit to a trajectory that will reenter the Earth within five years.

This mission to observe unprepared objects in orbit at close range is an unprecedented achievement in space operations. It has provided useful data for ADR missions, such as JAXA's CRD2 Phase II, significantly reducing risk and demonstrating essential technologies for approaching unprepared objects that will be critical for future RPO and on-orbit servicing.

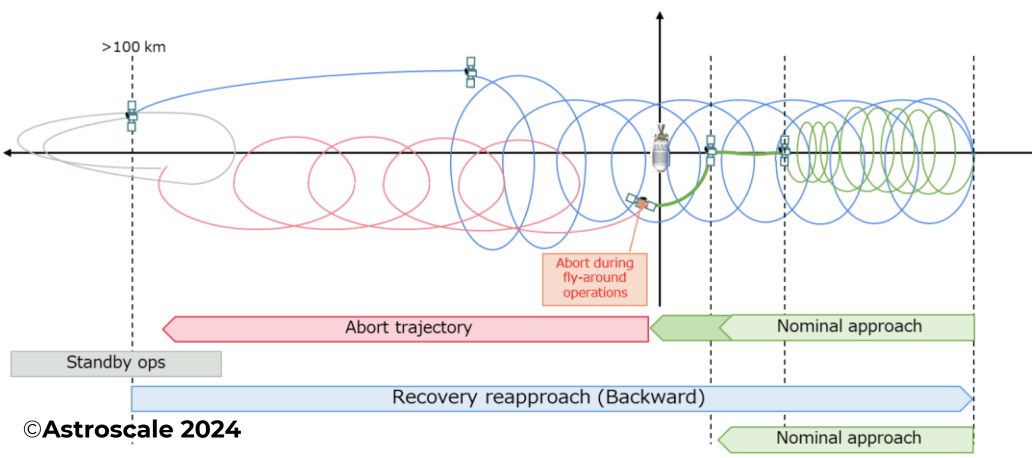

Fig. 19 : Overview of trajectories during abort and recovery

References

1) JAXA, Commercial Debris Removal Demonstration (CRD2) https://www.kenkai.jaxa.jp/research/crd2/crd2.html
2) JAXA, 9th Space Debris Workshop, A03 Latest updates on JAXA Commercial Removal of Debris Demonstration (CRD2), Pg.29, 202 https://jaxa.repo.nii.ac.jp/record/47761/files/AA2130003000.pdf
3) JAXA, 10th Space Debris Workshop, C13 Study of Technology Demonstration Scenarios of CRD2 Phase2 Aiming Sustainable Debris Removal, Pg.555, 2022 https://jaxa.repo.nii.ac.jp/record/49191/files/AA2230027000.pdf
4) H. Krag, Head of ESA's Space Debris Office at SWF Summit for Space Sustainability, June 26, Pg.10-11, 2019 https://swfound.org/media/206467/02_krag.pdf
5) ESA'S ANNUAL SPACE ENVIRONMENT REPORT, Pg.101, 19 July 2024 https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf
6) Seita Iizuka, Yusuke Ota, Yuki Seto: 32nd Workshop on JAXA Astrodynamics and Flight Mechanics - ELSA-d demonstration achievement in orbit - , pp 32, 2022
7) Keita Iizuka: 66th Japan Society for Aeronautical and Space Sciences 4G09 Status of ELSA-d project – Operation & demonstration achievement –, 2022
8) Keita Iizuka: 66th Japan Society for Aeronautical and Space Sciences 1O04 Status of ELSA-d's de-orbit operation, 2023
9) Eijiro Atarashi and Hisashi Inoue: 68th Japan Society for Aeronautical and Space Sciences 4G18 Status of ADRAS-J project - Summarization of ADRAS-J project -, 2024
10) Yu Nakajima, Toru Yamamoto, Naomi Murakami, Koji Yamanaka : JAXA, 6th Space Debris Workshop, C3 A research toward guidance, navigation, and control for a Non-CooperativeTarget, Pg.164, 2015 https://jaxa.repo.nii.ac.jp/record/3730/files/AA1530025000.pdf
11) Yuki Seto, Hisashi Inoue, and Aleksander Lidtke: 66th Japan Society for Aeronautical and Space Sciences 4L05 Rendezvous Orbit Control by ELSA-d, 2022
12) Simone D' Amico and Oliver Montenbruck, "Proximity Operations of Formation-Flying Spacecraft Using an Eccentricity/ Inclination Vector Separation", JOURNAL OF GUIDANCE, CONTROL, AND DYNAMICS, Vol. 29, No. 3, 2006
13) Roger Gutierrez-Ramona, Aleksander Lidtke, Kevin Charls, Harishkumar Sellamuthu, Andrew Alder,Lukas Steindorf, Yuki Seto, Thaisen Chant, Hisashi Inoue: The 75th International Astronautical Congress, Hitting a moving target – ADRAS-J launch targeting to rendezvous with a derelict resident space object, IAC–24–A6,IP,106,x87269