SOR

Executive Summary Report

Abstract

ESA has decided to break the ground into sustainable Space development by pioneering this landmark mission Clearspace-1 and selected ClearSpace to lead it. ClearSpace-1 is more than a ground-breaking mission and a high-impact technical accomplishment. It is the first corner stone on the road to a future Space debris removal service at an affordable cost. In collaboration with ESA, ClearSpace and industrial partners have set out to create a precedent with a transformative impact on the Space industry. ClearSpace-1 aims the capture and removal of a payload adapter, the VESPA, an ESA-owned object.

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1 Introduction to Clearspace-1 Mission.

1.1 Scope of Clearspace-1 Mission

The objective of the Landmark ClearSpace-1 mission will be to demonstrate the complete value chain of Active Debris Removals by removing an ESA owned object (a VESPA Upper Part orbiting at 500Km altitude) by 2025.

The motivation for this project is that today there are more than 3’000 failed satellites orbiting Earth and less than 2’000 “live” ones... These uncontrollable objects present risks of explosions or collisions with other satellites. Each such event increases the number of debris dramatically, in turn increasing risks of further collisions. In a context where the number of satellites launched every year is growing rapidly, the population of man-made debris orbiting Earth has exploded over the last ten years. The next big challenge is keeping Space clean in order to insure sustainable growth in the future. To do so Active Debris Removal is one mitigation measure as it can be observed in the simulation shown in Figure 2.

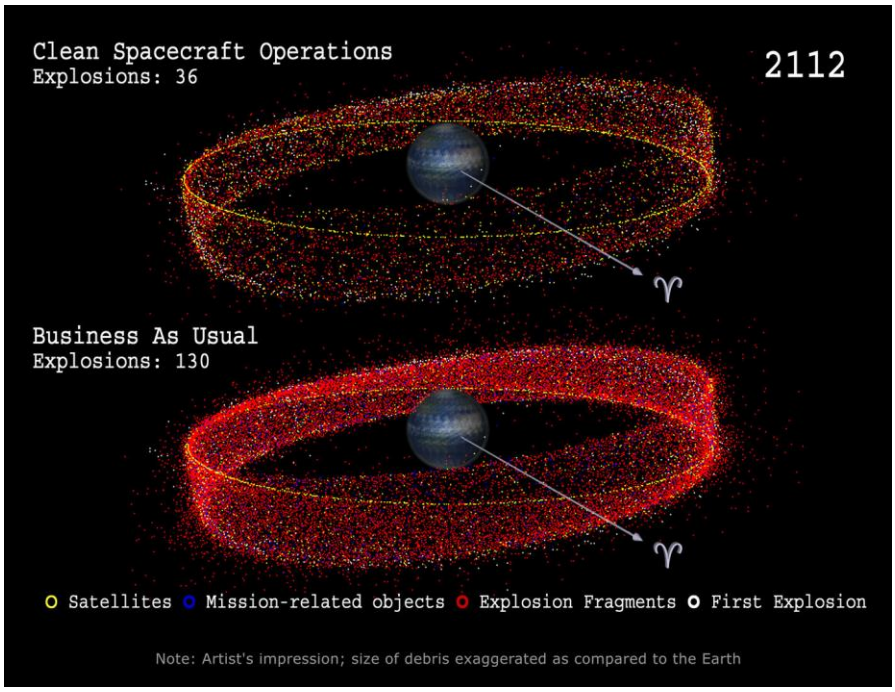

Figure 1 : Simulation of the GEO environment with and without mitigation measures (credit ESA)

1.2 What Clearspace-1 needs to do

ClearSpace-1 mission's main goal is the capture and removal of a payload adapter, the VESPA, an ESA-owned object the latest by end of 2025. It also aims to demonstrate the basic technical building blocks of the complete assisted removal value chain (technologies and operations): uncooperative rendezvous, capture (including stack stabilization), stacked de-orbiting, and target release, enabling a versatile and safe commercial assisted disposal. Finally, this in orbit demonstration shall enable an economically viable commercial service.

The capture and removal operation can be divided in several phases, which are:

- Launch at into space at 500km altitude
- Perform LEOP, commissioning and phasing to the target
- Rendezvous with target
- Capture and stack the target
- De-orbit the target

The concept of operations is detailed on Figure 2.

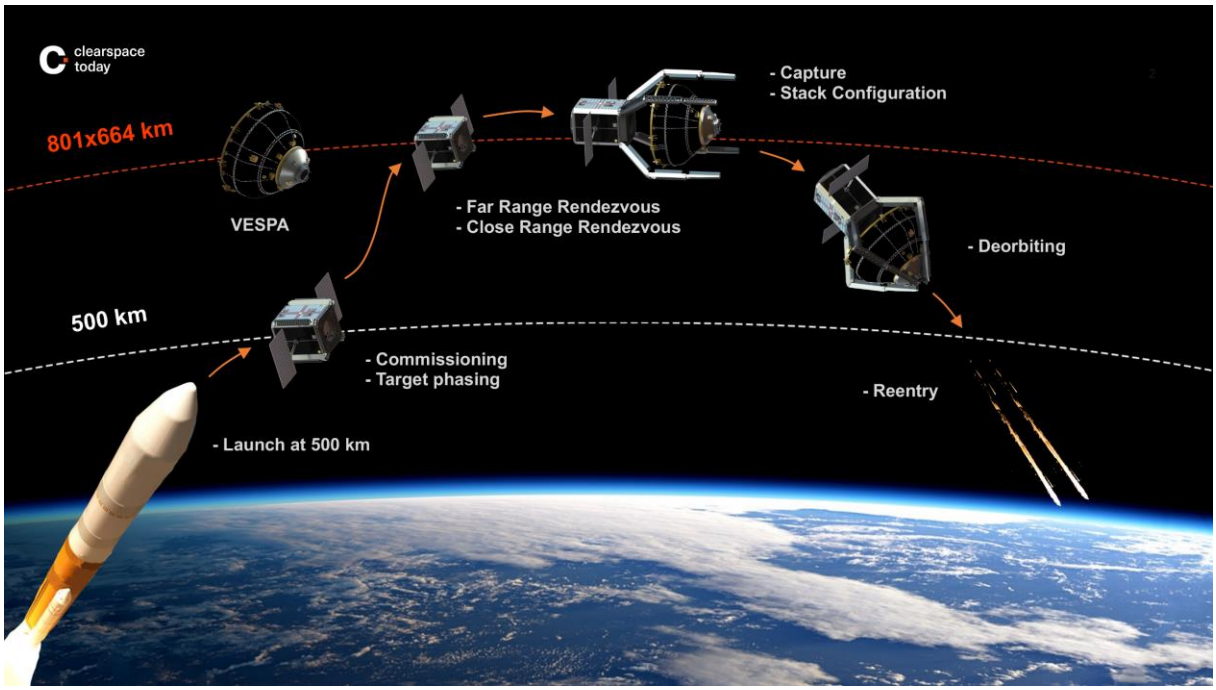

Figure 2: VESPUP Mission Service Concept of Operation (Credit ClearSpace; Vega illustration © ESA / Jacky Huart, 2015)

For the initial service, the target does not have a sun-synchronous orbit and its mean local time drifts at about 20deg/year. The target local time of ascending node will be about 13h45 in November 2024, which constraints the possible insertion orbits. After separation and post-launch detumbling, standard commissioning of the platform is performed, with the addition of functional testing of the capture mechanism and the rendezvous sensors.
The servicer matches the target orbital plane through nodal precession and inclination corrections, performs orbit raise and phasing to place itself 30km along-track behind the expected target location and detects the target.
The servicer gradually and safely closes the distance using Angles-Only Navigation.
The servicer gathers and downlinks data on the target and rendezvous sensors and commissions the relative GNC to perform close proximity trajectories getting gradually closer to the target and finally captures the target.
The combined stack of target and servicer is detumbled. Capture data is transmitted and the center of mass of the stack is aligned with the thrust axis. The stack is prepared for reentry and de-orbited.

1.3 Organization of this paper

Four questions will be answered in the next four chapters: what are the boundaries of the Clearspace-1 mission? How the mission is executed? How can we enable success? And what do we see when we re-assess the development on a regular basis?

2 Boundaries of Clearspace-1

2.1 Clean Space Initiative and ADRIOS Program

Clearspace-1 is a mission requested by ESA's Clean Space initiative. The objective of Clean Space is guaranteeing the future of space activities by protecting the environment. With the Clean Space initiative, ESA will devote increasing attention to the environmental impacts of its activities, both on Earth and in space [1.]. Clean Space has three branches as shown in Figure 3, reflecting its mission to assess the environmental impacts of Agency programmes to finding ways to address them, and contributing to a more sustainable and competitive European space industry.

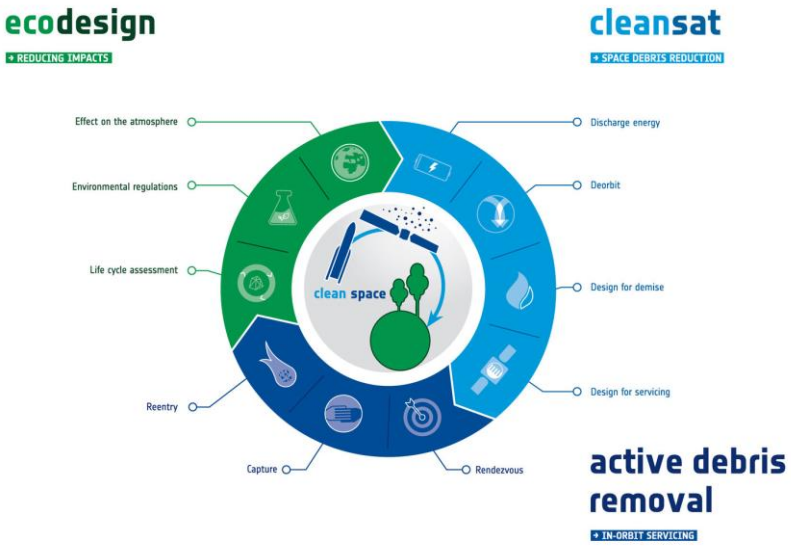

Figure 3: Clean Space Initiative and its branches

These branches are:

- EcoDesign: embedding environmental sustainability within space mission design
- CleanSat: developing technologies to prevent the creation of future debris
- In-orbit servicing/Active Debris removal: removing spacecraft from orbit and demonstrating in-orbit servicing of spacecraft.

Clearspace-1 is a mission under the branche Active Debris Removal and In Orbit Servicing.

2.2 Planning

The global timeline of the Clearspace-1 mission is given in Figure 4.

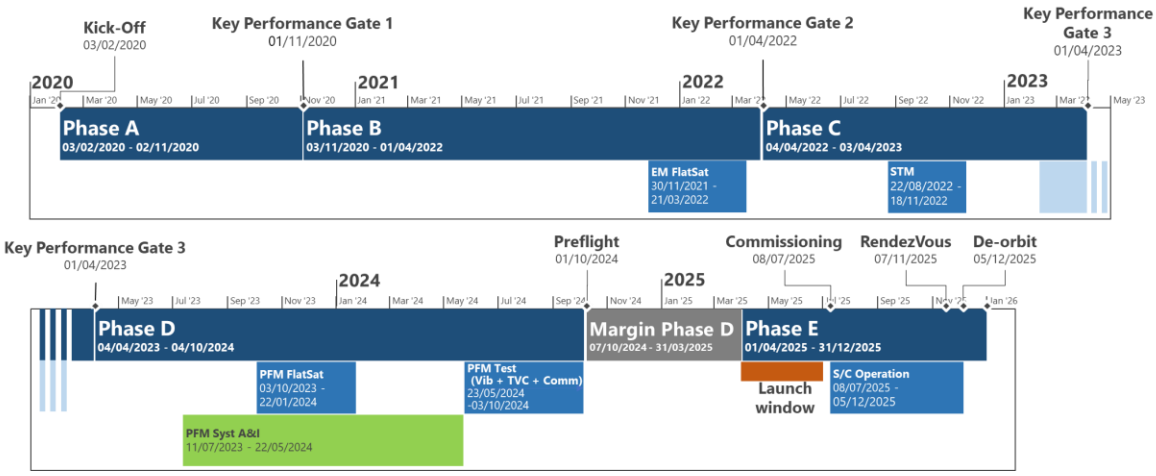

Figure 4 Clearspace-1 mission timeline

At the time of the release of this document, the mission and its development has been funded for the period 2020 to 2022 during the CM Space19+.

At the end of the period 2020-2022 the Phase A and B will be concluded with the Key Performance Gate 1, respectively 2 (described later in the text) with the production and test of the EM flatsat. During period 2023-2025, the phase C of the mission will be well advanced and completed with KPG3 in Q1 of 2023. Pending approval to continue in the MC 2023-2025, the phase D will start, leading to the PFM Model fully tested in 2024. Pre-flight readiness review will take place at the end of 2024; however, 6 months development margin is considered, giving a launch window starting from April 2025 and lasting 3 months. The mission operations must be closed at the end of 2025 with the reentry of the chaser and the VESPA.

2.3 Stakeholders

Until the kick-off of the mission, the systems design studies and some of the core technologies for the capture were performed under ClearSpace own funding. In November 2019, at the ministerial conference, subscriptions were received from Switzerland, UK, Germany, Portugal, Poland, Sweden, Czech Republic and Rumanian. The final industrial consortium is not yet completed

Active stakeholders will be therefore the European delegations, European industry itself. Within ESA, several directorates are stakeholders due their involvement in the system studies, such as the mission analysis team, operations team and space debris team at ESOC, German, as well as the TEC support team and communications office, and the General Studies Program team, all at ESTEC, The Netherlands, plus the Clean Space team at ESA headquarters, France.

When the mission will be launched, several stakeholders will be active such as the Arianespace launcher provider, satellite operators and ITU (International Telecommunications Union through the Swiss Federal Office for Communication).

3 Executing Clearspace-1

This section presents a preliminary overview on how the Clearspace-1 mission will be executed and what are the driver for the design.

3.1 Target

Clearspace-1 aims the capture and removal of a payload adapter, the VESPA (VEGA-C Secondary Payload Adaptor), an ESA-owned object. The 2m diameter and 1.6m height structure weighs 112 kgs and orbits earth at an 801 x 664 km altitude.

The choice of the VESPA is especially well suited for a low risk technology demonstration as it does not have extruding appendages that may be fragile or force risky/undemonstrated navigation and control strategies.

Recent and preliminary investigations of target attitude seen in Figure **5** there is only a slow variation of the observed magnitude of the object over a span of about 3 minutes. Thus, the VESPA Upper Part is expected to tumble at a low rate.

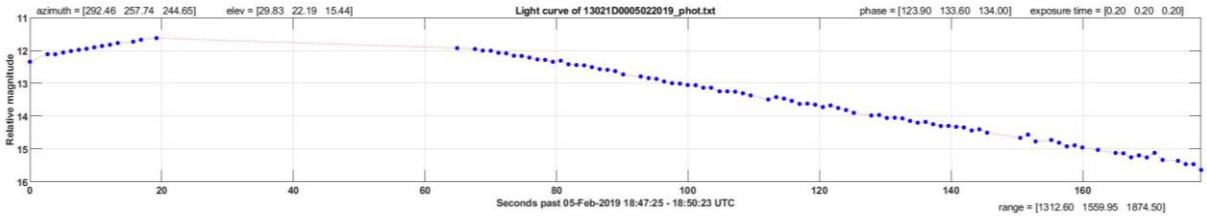

Figure 5: Light curve observation of VESPA (AVUM) NORAD ID 39162

3.2 Clearspace-1 objectives and driving requirements

The initial service requested by ESA is a key milestone to the development of a consortium's commercial service, which is currently tailored at the assisted disposal market. The technical solution is thus designed to address this specific type of on-orbit servicing.

The viability of an assisted disposal commercial service on the long term depends on a few key factors that can be summarized as such:

- Offer a commercial option with an affordable cost of removal per space object,
- Offer a reliable, safe and debris-clean solution,
- Offer a responsive solution that can adapt to several types of objects and that can potentially offer a rapid execution of object removal,
- Offer a service that can cover semi-cooperative (prepared targets), and uncooperative targets.

Assessment of the greatest marked potential and volume currently lies in target failed satellites with a mass up to 860 kg of this service offer. This service addresses the case of large constellations. However, we expect that ESA showing the path to space cleaning will create similar behaviours among other space agencies, which means that another segment of the market will be institutional, with institutional targets. Figure 6 below shows the type of expected targets to service in a first round. We note that most of the potential customer satellite do not have conventional circular adapter rings, nor prepared interfaces.

The chaser is designed to be adaptable to multiple body shapes and tumbling rates.

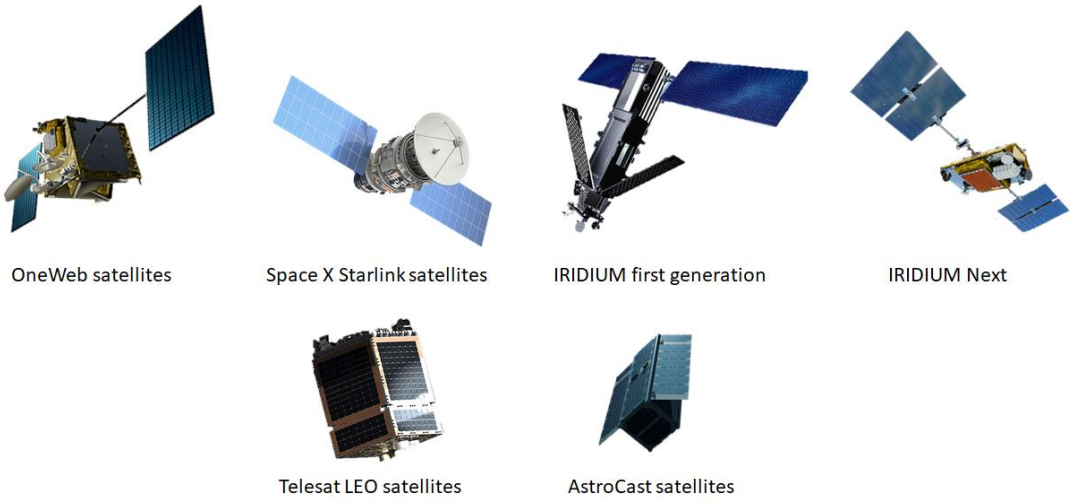

Figure 6: Current Targets driving the Servicer design.

The ESA proposed initial service requirements have been adapted for our consortium commercial objectives, maximizing the technological demonstration while reducing the risk for a first demonstration mission, since a failure during this first mission would create a set-back for the overall community and for the greater objective which is the long-term sustainability of space operations.

4 Enabling Succes

Unlike the traditional procurement of ESA, Clearspace-1 mission is a key milestone to the development of commercial service made available to space players. The mission is the natural product of the Clean Space initiative.

4.1 Clearspace-1 Consortium

The Clearspace-1 service gathers the agility of a start-up to adapt to the new rules of the space industry and the backbone of solid heritage from the industrial partners. At the release of this document the consortium is not yet finalized and the next sections are preliminary.

Core Team

In a nutshell, the project is led by ClearSpace, a spin-off of EPFL, which was originally created to implement the CleanSpace One (CSO) mission. It has been joined in its commitment to serve the long-term sustainability of space infrastructures by industries that want to make the turn of the “new space” and that have already prepared for it. All of these partners are committed to make a commercial service and are ready to keep the quality yet provide a design-to-cost approach to the service development.

Three academic partners provide key developments and support to the service. EPFL has laboratories and a Space Center that are used to working with and for industries, that understand the stakes and are committed to providing the technological stones of the project. The RGL, CV, ESL and MSL

laboratories are involved in the relative pose estimation, its development and hardware implementation.

Finally, ESA Space Safety's team will be a very important member, bringing years of experience in this field. A strong relationship exists already between ClearSpace and the Clean Space manager, Clean Space system engineer, and direct higher management within ESA's TEC directorate. The team members were mostly present from the beginning i.e. active in space sustainability studies even before Clean Space was created.

4.2 Key Performance Gates

Traditionally ESA is the leader in a procurement and steps the phases of the development of a system with reviews, which allows to assess the maturity of the subjacent technologies. Generally, all subsystems shall pass the review before the following phase can be initiated or the implementation of hardware can start. Clearspace-1 is a pilot-project which aims to develop an ADR commercial service under the accompaniment of ESA, such that the traditional approach is not applicable. However, it was decided to set gates to assess the development and allows, if necessary, to stop the project, at a point where technologies achieve a significant level of readiness. Along the mission timeline, 3 Key Performance Gates will be set and articulated around the following evaluation categories: Management, Systems and Technologies development. At each gate, an evaluation board will assess collegially the success of pre-defined criteria in those categories and ESA will reserve the right on continuation of the service procurement.

4.3 Culture

Clearspace-1 mission occurs at a paroxysm of awareness on environment issues on Earth: climate change, pollution of natural resources and now endanger of our space environment. Indeed, the use and access of space is of paramount, since Information, GPS, mobile telephony, meteorology forecasts or remote crops survey are few examples of benefits that fully depend on spaceborne services. ClearSpace and Clearspace-1 benefit from the public young awareness on this problem, as it confirmed by the huge press coverage of the ADRIOS program and Clearspace-1 mission after the ministerial conference Space+19.

5 Clearspace-1 Developments Status

While the Clearspace-1 mission has not yet started as the issue of this document, this section shows the current state of the development of the critical technologies.

5.1 Maturity of Critical Technologies

The Clearspace-1 mission requires particular technologies which are:

A versatile capture system, which development encompasses:

- Highly reliable proximity sensing system
- High level control algorithms
- Contact dynamic simulation model

Advanced GNC and target attitude estimation:

- Advanced GNC solutions for ADR, ie. GNC algorithm and solutions to capture and de-tumble the Chaser with the target attached via the capture mechanism

- Pose estimation of the target using vision-based algorithms

Advanced sensors for ranging:

- Miniaturized RF Radar
- Miniaturized 3D ToF Flash LIDAR

5.2 Development Strategy

The overall system design, development and verification (DDV) approach is tailored for a flight segment that will have on one side platform heritage and, on the other, new rendezvous payload developments. The ground segment major elements will have much heritage and thus follows a non-critical path.

6 Conclusion

The Clearspace-1 mission is a demonstration of an ADR service aiming to remove by end of 2025 the VESPA Upper Part that was launched during Arianespace VEGA VV02. It is a challenging mission that requires new developments as capturing an uncooperative space debris using a spacecraft, and then de-orbiting it, has never been done before. It allows Europe to take the lead in ADR technologies. Doing so this mission is creating a precedent, a tipping point, after which operators will have a new option for PMD and ESA is providing a launching ramp for this commercial service.

The service will take this opportunity to test critical technologies that will enable an affordable commercial service. As much as possible de-risking and testing is planned to be compliant with debris mitigation requirements and the French law. The Clearspace-1 mission demonstration proposed is a combination of high-heritage elements and know-how, and low TRL but innovative capture service solutions. The approach to de-risk the low TRL elements is presented and features pre-developments before the start of the initial service, on-ground testing and several flight tests once in orbit before the final operations. Preliminary risk assessments lead to the conclusion that back-up exists to ensure the service. The relative navigation approach includes both complex algorithms to be tested in flight for and simpler, more robust algorithms that will de-risk the capture of the target.

The mission has been granted thanks to the push and the strong collaboration of ESA Space Safety Office, ClearSpace, industry and delegations.

Clearspace-1 mission has received much attention in the media since more than 70 press articles have been released since the CM Space+19, all around the world and in prestigious medi like Space News, Le Figaro, The Guardian, The Financial Time; or in the social media trendings like Reddit.

7 References

[1.] Clean Space website, www.esa.int/cleanspace