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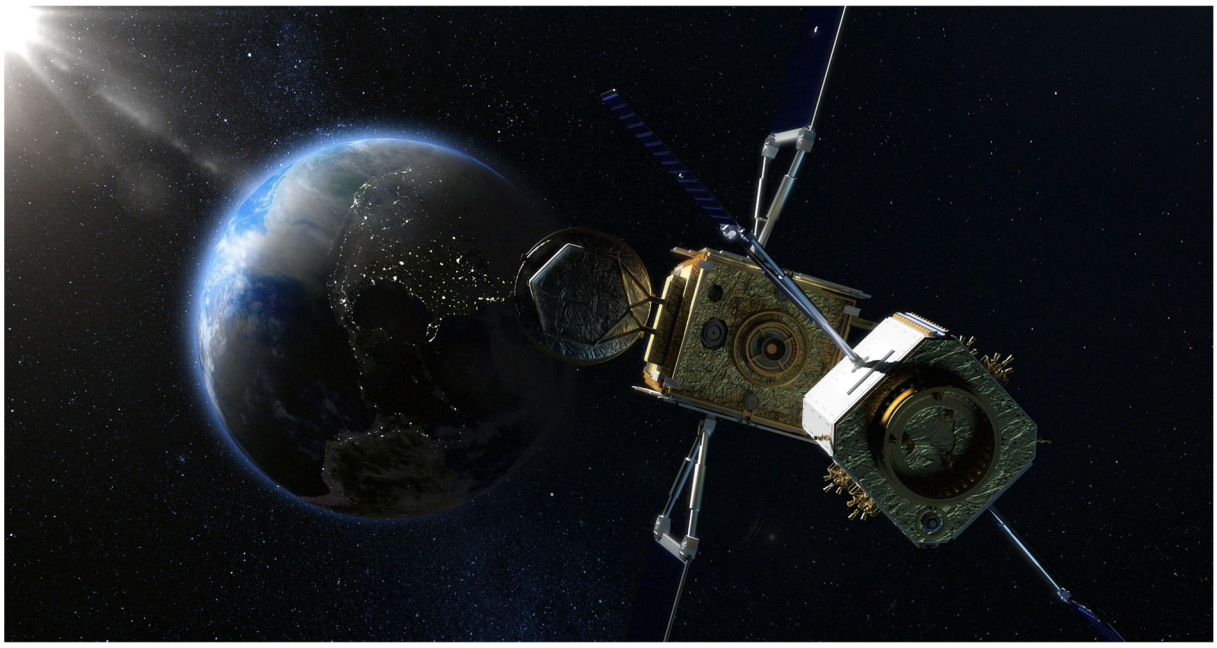

ENCORE – In-Orbit Servicing of an Operational Spacecraft

Executive Summary Report

1 Introduction

This document provides the Executive Summary Report of the IOSPR for the ENCORE Mission. An overview of the ENCORE mission is detailed, together with a summary of the activities performed as part of the maturation phase.

2 In-Orbit Services

The development of In-Orbit Services (IOS) to support the growing space infrastructure is critical to ensure the reliable and sustainable provision of vital services to Earth-based systems. IOS include transportation, disposal, refuelling, life-extension, bring into use, inspection and repair, and open the door to new in-space capabilities such as manufacturing, assembly and recycling. The ability to service satellites not only enhance the safety and sustainability of space activities, but also makes the space infrastructure more resilient and enables new applications. IOS change the paradigm under which space operations are conducted and moves us towards a more circular space economy.

Demand for IOS is growing and represents both a significant market opportunity for early-mover companies and a strategic capability for Europe and ESA member states. ClearSpace aims at seizing this opportunity by developing a Geostationary Earth Orbit (GEO) life-extension service. Beyond the strategic value of IOS core technologies, satellite life-extension is one of the most promising and immediate commercial IOS opportunities. The life-limiting factor for most high-value satellites is fuel, and until now, operators have been forced to retire fully functional satellites that could otherwise continue to provide services to customers and generate revenue. Providing life extension services for such satellites has a clear business case, as operators are willing to share with the service provider the revenue enabled by the life extension.

3 Market Demand for IOS

The market for life-extension services for GEO satellites is expected to remain healthy over the foreseeable future: over the last 20 years, an average of 22 new GEO satellites have been launched per year. In total, ClearSpace expects there will be 370 potential Client satellites that will reach their end of life due to the limited fuel they have remaining over the 2026-2041 period. With a number of servicers planned to be launched by ClearSpace over the coming decades, each able to provide multiple life extension services, ClearSpace can deliver services to a large number of Client satellites, amounting to a significant portion of the total market size. ClearSpace believes a strong market penetration rate is feasible, as more than 30% of all the potential satellites belong to just 7 satellite operators.

4 The ENCORE Mission

ClearSpace proposes a mission to extend the service life of a geostationary (GEO) communications satellite that will have depleted all its fuel in 2028. The ENCORE (Europe's New Commercial Orbital Revenue Extension) mission is an opportunity for ClearSpace to leverage its existing developments performed on other missions to accelerate its market penetration and diversify its service offerings.

4.1 Mission Objectives

The ENCORE mission objectives are summarized in Table 1.

Area	Objectives
Design and Development	• Specify and design a servicer.
Rendezvous and Docking	• Validate the rendezvous, docking and release capability in-orbit on a cooperative Customer spacecraft in GEO graveyard orbit. • Dock to a Customer spacecraft in the GEO arc without interruption of the Customer spacecraft. • Capability to dock to multiple GEO spacecrafts up to 15 years of servicer lifetime.

Area	Objectives
	• Dock to a Customer spacecraft. • Release a docked Customer spacecraft in the GEO graveyard at the end of the life extens ion.
Life Extension	• Perform a life extension mission of a Customer spacecraft in the GEO arc. (Life extension includes providing orbit and attitude control of the Customer spacecraft in its GEO location).
Refuelling	• Prepare the servicer to be refueled in-orbit after its first life extension and completion of the ENCORE mission.

Table 1: The ENCORE mission requirements.

The scope of this first mission with ESA will involve the design, development and launch of a servicing vehicle (servicer), followed by an in-orbit validation of the servicer rendezvous and docking capabilities.

4.2 Mission Profile

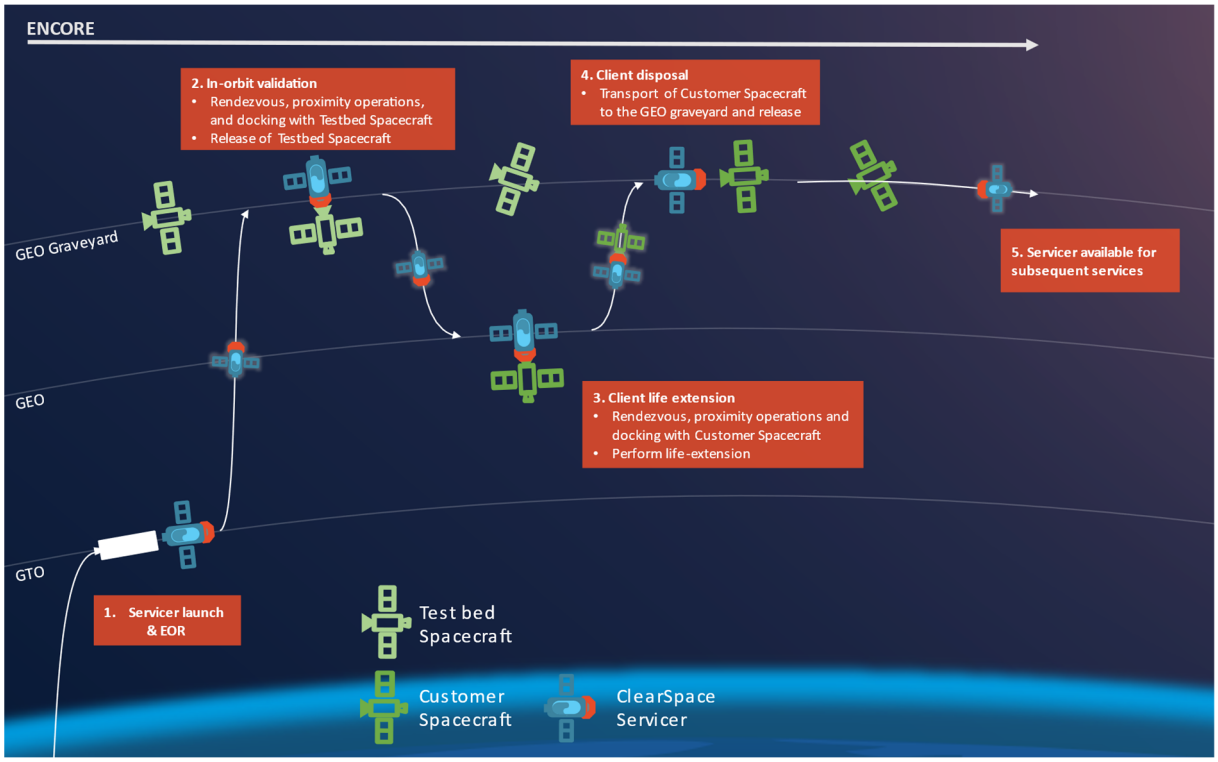

Figure 1: The ENCORE Mission Profile

After its launch, the ENCORE servicer will first validate the complex docking and takeover procedures for station keeping and attitude control on a functional, retired communication satellite in the GEO graveyard. Upon successful completion of this de-risking activity, the ENCORE servicer will separate from this retired satellite and move on to service a high-value, operational satellite, extending its ability to serve customers and generate revenue. The servicer will use its on-board navigation and rendezvous sensors, and its robotic docking system to securely attach to the Client satellite and assume responsibility for its attitude control and station keeping functions. Upon completion of the service, the Client satellite could be ferried to the GEO graveyard for disposal. The full mission profile is shown in Figure 1.

ClearSpace's servicer can dock and undock with Client satellites multiple times, and can be refuelled, enabling ClearSpace to service subsequent Clients.

4.3 Mission Timeline

The overall timeline for the ENCORE mission starting from the kick-off of the project (not including the maturation phase) to the implementation of the Client life extension service is shown in Figure 2. This highlights the key milestones for the servicer development, as well as those for the mission operations.

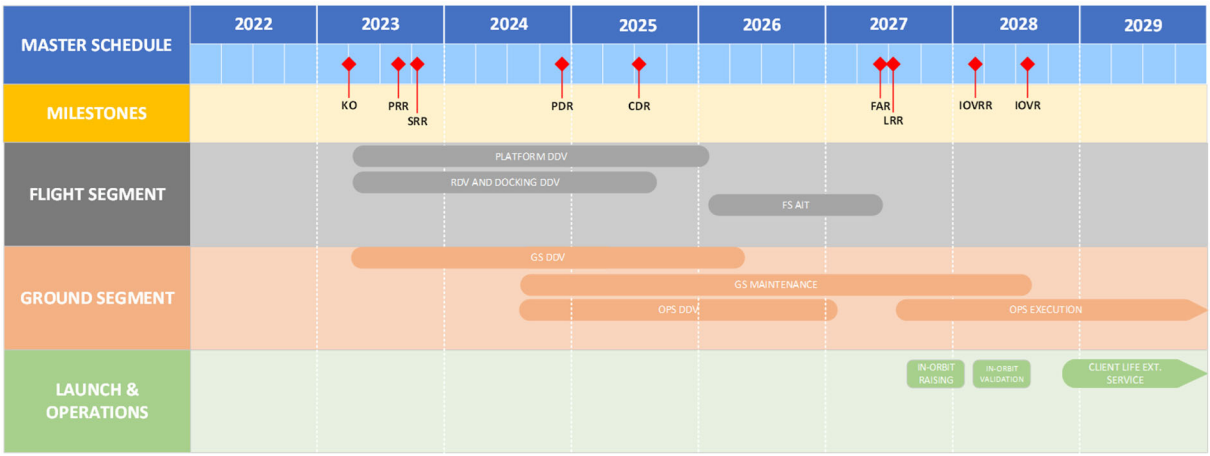

Figure 2: The ENCORE Mission Timeline

A kick-off date of in Q1 of 2023 is assumed with around four years of development, verification and validation activities planned. Launch of the ENCORE servicer is expected in Q3 2027 and the onset of the Client satellite life extension service is expected prior to the end of 2028. To meet this aggressive timeline, the program will be developed strictly in accordance with commercial industry best practices, implementing lean development methodologies.

4.4 System Description

The ENCORE system is summarised in Figure 3.

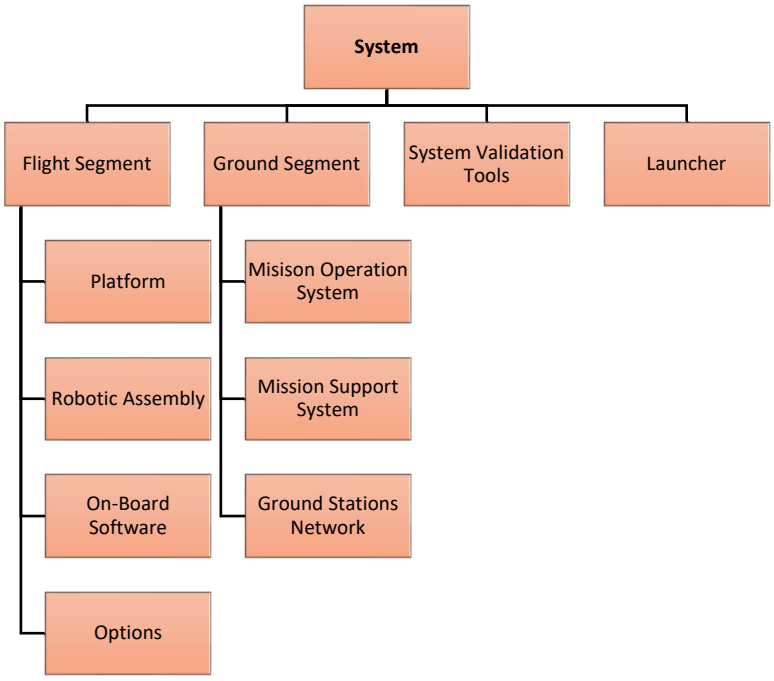

Figure 3: The ENCORE system.

The Flight Segment consists of the servicer which includes the GEO platform, robotic assembly, and on-board software. The GEO platform will provide the data handling, attitude control, power, telecommunication, electrical propulsion, chemical propulsion, thermal control, and structure. The robotics assembly consist of the docking system used to capture and connect to the Client satellite and relative navigation and rendezvous equipment used for the rendezvous and proximity operations.

The Ground Segment consists of three core systems: the mission operations system which encapsulates all the ground handling activities, required for the operation of the servicer; the mission support system which is used to execute the mission from the ground and the ground station networks which connect the mission operations system with the servicer.

The Flight and Ground Segments are supported by the system and validation tools required to for the assembly, integration, testing and verification activities during the servicer development.

The launch vehicle is anticipated to be the Ariane 6.

4.5 Risks

Table 2 represents a sample of risks that have been identified for the mission with proposed mitigation strategies.

Category	Risk	Mitigation Strategies
Technical	Unanticipated programmatic challenges may be introduced, caused by ClearSpace's shift from LEO to GEO operational environment, resulting in mission delays and over costs.	• Hire SE and AIV talents with experience on GEO platform. • Partner with experienced GEO platform provider. • Partnering with the world's most experienced GEO satellite operator as a customer.
Technical	The servicer is unable to dock to the target satellite, caused by unforeseen technical complexities, resulting in mission failure.	• Take proximity operations experience from CS-1 and implement passively safe rendezvous trajectories. • Perform ground simulation and testing of the mechanism and associated robotics. • Abort and repeat capture attempts in orbit. • Leverage GEO satellite operator's experience.
Commercial	The retirement window of the target satellite may be missed, caused by delays in the development plan or launch campaign, resulting in inability to perform the life extension service on the target satellite.	• Ensure regular monitoring and review of the schedule to identify any potential delays as early as possible. • Include adequate schedule margins in the program. • Baseline a target spacecraft that can wait in the graveyard orbit (without passivating) for some time. • Include a backup target satellite. • Work with a customer that has an extensive fleet, such that other targets could be considered if timelines no longer align.
Commercial	The servicer may need to be re-designed, caused by the need to meet the requirements of a specific Customer, resulting in the business case no longer being commercially viable.	• ClearSpace already approached multiple GEO operators for the proposed service and plans to collaborate with more than one operator in the design phase to take multiple GEO platforms into account in its mission and product design.

Category	Risk	Mitigation Strategies
Financial	Delay of ClearSpace fundraising activities, caused by lack of investor interest or opportunities, resulting in insufficient co-funding for the mission.	• ClearSpace financing will be well established prior to contract award. • Assemble an investor team with a vested interest in scaling the company for commercial leadership.

Table 2: A sample of risks identified for the ENCORE mission.

5 Maturation Phase

The maturation phase has seen extensive work completed to mature and progress all aspects of the mission including the technical solution, cost estimation, legal and regulatory aspects, potential industrial consortium, and customer engagement.

5.1 Technical

5.1.1 Flight Segment

A significant amount of work has been completed through the maturation phase to further define the key aspects of the flight segment. ClearSpace has worked closely with Deimos to perform the mission analysis and a new mission profile has been derived. Trade-offs have been performed for the different launch injection options and the electrical orbit raising (EOR) scenario. The output of simulations performed have been used to refine the delta-V budget, the EOR duration and radiation analysis.

The requirements have been further defined in a top-down approach starting with the Customer and ESA requirements, and ClearSpace business requirements. The mission and system requirements specifications were then derived and consolidated, and the lower-level subsystem specifications were also drafted. The approach to the standards the mission will adhere too were also discussed.

The approach for the development and validation of the on-board flight software was defined through work completed by Critical Software, building on heritage from the ClearSpace-1 (CS-1) mission.

Key aspects of the system design have been consolidated, starting from a functional decomposition of the system and product tree. The technical budgets (delta-V, dry mass, propellant, RF link and power budgets) have been further refined and show a consistent technical preliminary solution based on existing products and heritage. The main system analyses have been identified and a first loop of the radiation, sunlight shadowing and RF analyses have been performed.

One of the main outcomes of this phase has been to mature the preliminary design of the servicer. A co-engineering approach was adopted by ClearSpace and OHB Systems to define the servicer bus. This is based on an existing commercial platform designed for GEO missions, tailored to meet the ENCORE requirements. To steer the tailoring exercise, a gap analysis was performed, followed by design activities to address the gaps. This included downsizing of the structure, thermal control, and harness, downsizing of the electrical power subsystem, adaptations to the propulsion and communication subsystems and replacement of the telecommunications payload.

One of the key subsystems as part of the ENCORE servicer is the docking system. Through the maturation phase, the concept has been further matured. Following the definition of the key requirements, detailed trade-offs were performed to evaluate the suitability of various docking mechanisms. The selected concept is a new, confidential design which is characterized by its mechanical robustness, low mass, heritage design, higher reliability, and low recurring costs.

Another key subsystem is the guidance, navigation and control (GNC), and rendezvous suite required for proximity operations. The GNC architecture was further refined, drawing on heritage from the CS-1 mission. The rendezvous sequence, split between the far-range, mid-range, and close-range was also consolidated. Options for the rendezvous sensors were explored.

5.1.2 Ground Segment and Operations

The ground segment design and operations concepts have been further defined. A key aspect of this was the specification of the Ground Station Network (GSN) requirements and the selection of an appropriate provider for this. There is a need to provide coverage of the entire equatorial arc and the maturation study has shown that this requirement can be met using a single GSN provider. Analysis of the most popular TCR frequency bands used by GEO satellites was also performed, resulting in the selection of the Ku and C bands for the servicer design.

The current ClearSpace Mission Operations System design to accommodate the functionality required for ENCORE was also investigated and it was found that the overall design is mostly already suitable for ENCORE, with the addition of a Customer Interface System the only change.

The concept of operations, including entry criteria, high-level operational activities, and exit criteria, has been defined for each mission phase. This includes the definition of the phase transition process, the mission operations timeline, and a list of Go/NoGo gates. The operations concept has been iterated in co-engineering sessions with the Customer and it is clear a coordinated operation is required. Work has been done to define the boundaries, communication protocols, and the data flows between ClearSpace and the Customer.

5.1.3 Launcher

Different launch options were investigated with Ariane 6 and a standard GTO considered. Different launch configurations were also investigated to optimize the launcher volume and mass allocation, to help minimise the launch cost. Space X Falcon 9 has also been investigated for future missions.

5.2 The Mission Cost

Through the maturation phase ClearSpace has endeavoured to further refine their cost estimates for the mission. This was achieved through rough order of magnitude costs received from current and prospective partners, applicable cost estimates from ClearSpace's other missions and ClearSpace internal cost exercises. The mission is anticipated to be funded largely by ESA with a co-funding contribution provided by ClearSpace.

5.3 Industrial Organisation

ClearSpace, as an In-Orbit Service (IOS) provider, will lead the proposed industrial organization as Service Prime. The CS-1 and CLEAR missions have ensured that ClearSpace has already established strong partnerships with organisations throughout the ESA Member States. These existing relationships have been complemented with a thorough review of the European supply chain to identify potential partners for the ENCORE mission. Therefore, the industrial team setup envisaged for ENCORE will combine the expertise and experience internal to ClearSpace with the key capabilities of organisations across Europe.

ClearSpace has already established a promising industrial consortium through the maturation phase as shown in Figure 4.

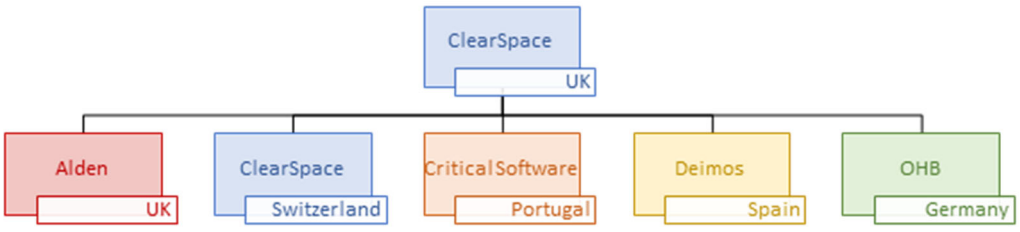

Figure 4: The ENCORE consortium through the maturation phase.

ClearSpace's UK entity led the activities as Prime with mission design and analysis support from ClearSpace's Swiss entity and Deimos. Platform expertise was provided by OBH Systems, flight software input from Critical Software and regulatory advice from Alden.

ClearSpace is very keen for new partners to join the ENCORE consortium and has dedicated activities to engage European industry and build interest in both the ENCORE mission and IOS program. ClearSpace has built close

relations over the past years with its partners, through which a balanced and effective industrial team may be established.

5.4 Legal and Regulatory

5.4.1 Launching State, State of Registry and Liability

As an IOS life-extension mission, a range of international and national legal, regulatory and policy matters must be considered. ClearSpace has worked closely with Alden to form a deeper understanding of these matters.

ClearSpace intends to procure the launch of the servicer from Arianespace through its UK entity and operate the servicer from the UK. Thus, ClearSpace will need to obtain a launch and operations license from the CAA, the UK regulator.

As Launching States of the servicer, France and the UK will both be liable for any damage caused by the servicer to a third party. By registering the servicer, the UK will retain jurisdiction and control over the servicer and thus accepts liability for it. As such, the UK will bear State-level responsibility for third-party liability. It is understood that the UK will transfer some of this liability to ClearSpace in the form of indemnification requirements imposed as part of the licensing process and that the UK will require ClearSpace to purchase third-party liability insurance coverage commensurate with the indemnification amount.

As the Client satellites for the in-orbit validation and life extension service are US-registered and US-licensed and will remain active during operations involving the servicer and the Client satellite, the US may also be considered as a launching state during these coupled operations.

5.4.2 Export Control

The mission must adhere to export control regulations such as the US International Traffic in Arms Regulations (ITAR), Export Administration Regulations (EAR), UK, European, and other export control regulations. These have been considered through the maturation phase.

5.5 Customer Engagement

ClearSpace has received tremendous interest in its proposed mission extension services from leading commercial GEO satellite operators across the globe. Some of the operators have signed Letters of interest in buying life-extension services and one particular GEO operator has been selected to be the Customer for ENCORE mission.

There are significant financial benefits that the Customer derives from ClearSpace's proposed services. Mission extension services are covered as operational expenditures, which allows the Customer to preserve its capital expenditure budgets for investments in new technologies, or to simply delay investments in replacement satellites. Information exchanges and the coordination of roles and responsibilities between the Customer and ClearSpace have been underway since the release of ESA's RFI. Over the maturation phase, ClearSpace engineers and program managers have held regular discussions with the Customer to work through high-level mission design options, operational constraints, and technical questions. ClearSpace has also met with the Customer's upper management to confirm their interest in ENCORE and future services.

The Customer, and other GEO operators, see significant value in IOS, and in mission extension services in particular. The Customer has a vested interest in supporting the development of a robust, competitive, commercial ecosystem for IOS.