AIRBUS	OOSS	Ref: ESYS-RP-OOSS-ADST-1000890819 Issue: 02 Date: Mar 12, 2021	ESYS

OSS Executive Summary Report

This document, technology or software does not contain data controlled under Export Control regulations

Export Control Regulation:

Export Control Rating Date: Mar 12, 2021
Export Control Rater: SCHAEFFER, Nicolas (Airbus Defence and Space) [FR]

Approval Information:

Name/Role:	Date:
JACOD, Vincent (Airbus Defence and Space) [FR] /	Mar 12, 2021 12:08:29 PM GMT

Left intentionally blank

Title

On-orbit Servicing Station (OSS) Study

Executive Summary Report

	Nom & Fonction	**Date**	**Signature**
Prepared by	OSS TEAM		
Verified by	JEAN-BAPTISTE BERNAUDIN *Study Manager*		
Approved by	JEAN-BAPTISTE BERNAUDIN *Study Manager*		
Authorised by	VINCENT JACOD *Head of EOS Chief Engineering France*		

Document type	**Nb WBS**	**Keywords**
RP		

Export Control Information

This document contains national, EU or/and US export controlled technology (data):

Yes ☐ **No** ☒

If No:

This document has been assessed against all applicable export control regulations and is **"Not Listed".**

If Yes, please complete the following as applicable:

1/ National Military / Dual-use export controlled content (other than US and UK)

Country/countries of origin for technology contained in this document:

☐ France ☐ Germany ☐ Spain ☐ other: [specify country]

☐ This document contains technology which is controlled by military export control regulation, classification [e.g. MLXXX / AMAXX]. Transmission abroad requires an export licence.

☐ This document contains technology which is controlled by national dual-use regulation, classification [XEXX], or by European Union dual-use regulation 428/2009 Annex IV as amended, classification [XEXX]. Transmission abroad requires an export licence.

☐ This document contains technology which is controlled by European Union dual-use regulation 428/2009 Annex I as amended, classification [XEXX]. Transmission within the EU does not require an export licence. Export from the EU requires an export licence.

2/ UK Export Controlled content

☐ This document contains technology which has been assessed against the UK Export Control list and is rated as [e.g. MLXXX / XEXXX]. Transfer from the UK requires an export licence.

3/ US (ITAR / EAR) export controlled content

☐ This document contains technology which is controlled by the U.S. government under [USML category number / ECCN] and which has been received by [legal entity] under authority of [licence number / ITAR exemption / EAR licence exception / NLR]. Any re-export or re-transfer of this document in part or in whole must be made in accordance with the appropriate regulation (ITAR/EAR) and authorization (e.g. DSP 5, TAA, ITAR exemption, BIS licence or licence exception, NLR).

☐ This document contains technology which is designated as EAR99 (subject to EAR and not listed on the CCL).

GLOSSARY

ESA	European Space Agency
CDF	Concurrent Design Facility
CONOPS	Concept of Operations
CS	Clean Space
GEO	Geostationary Orbit
I/F	Interface
ISMA	In-Situ Manufacturing and Assembly
LEO	Low Earth Orbit
OMAR	On-orbit Manufacture, Assembly & Recycle
OSS	O-orbit Servicing Station
P/F	Platform
P/L	Payload
RAAN	Right Ascension of Ascending Node
ROM	Rough Order of Magnitude
S/C	Spacecraft
TRL	Technology Readiness Level

1 INTRODUCTION

Through its Clean Space (CS) initiative, ESA has been devoting an increasing amount of attention to the environmental impact of its activities, including its own operations as well as operations performed by European industry in the frame of ESA programmes. In ESA's Technology Strategy, the Agency has identified as one of the four technology development targets Inverting Europe's contribution to space debris by 2030. The current activity is intended to support achieving the target.

On-orbit manufacturing and recycling is a concept that has been gaining momentum in the past years. A number of isolated technology developments have taken place recently. The reuse of space debris in orbit would turn a problem into a valuable asset.

However, before recycling a satellite, or manufacturing satellite parts in orbit, the understanding of the implications at system level is crucial as well as a clear view of the use cases that could benefit from this approach. Furthermore, a new AIT approach would have to be defined to fully benefit from the removal of constraints linked to on-ground manufacturing and launcher requirements. To address this complex issue, a comprehensive systems approach involving a multidisciplinary team and exploring synergies among the different possible scenarios and building blocks is necessary.

With this aim, ESA has set up the OMAR (On-orbit Manufacture, Assembly & Recycle) initiative. OMAR is a system approach aiming to give an overview of the most interesting applications, map the state-of-the-art and derive a roadmap for the development of the critical technologies. The proposed approach follows 3 steps:

- Step 1 – Preparatory small CDF study: screening the relevant mission scenarios, assess feasibility and derive systems architecture This activity is completed.
- Step 2 – Industrial studies: addressing main system segments based on established architectures (i.e. paradigm change on satellites design, on-orbit manufacturing/recycling plant, and logistics segment including servicing vehicles).
- Step 3 – Full CDF study: Preliminary system and subsystem design of all elements based on industrial inputs, consolidation of the mission scenario and concept of operations, definition of system interfaces between the different segments, evaluation of industrial and economic impacts of the proposed approach, definition of technology development roadmap.

In the frame of Step 2, three industrial activities will be carried out in parallel. These studies aim at understanding the possible strategies, system level impacts and potential benefits, while exploring the trade-space.

The On-orbit Servicing Satellite design study is part of this Step 2, alongside Mission Architectures and On-orbit Manufactured Spacecraft.

1.1 APPLICABLE DOCUMENTS

[AD 1] ESYS-TN-OOSS-ADST-1000709969: TN1 Preliminary Mission description and assumptions

[AD 2] ESYS-TN-OOSS-ADST-1000793956: TN2 Functional analysis for on-orbit station

[AD 3] ESYS-TN-OOSS-ADST-1000793975: TN3 Preliminary specification for on-orbit servicing station

[AD 4] ESYS-TN-OOSS-ADST-1000817922: TN4: Design Report of On-Orbit Servicing Station

[AD 5] ESYS-TN-OOSS-ADST-1000855216: TN5: Technology development plan and product tree for the on-orbit station

[AD 6] ESYS-RP-OOSS-ADST-1000888917: OSS Final Report

2 SCENARIOS DEFINITION

The starting point is a state-of-the-art looking at missions and projects under development or foreseen for On-Orbit Servicing. A look-out of technology aspects related to On-Orbit Servicing was also presented with a strong focus on robotics.

The second step derived Scenarios from the identified Use Cases. The outcome was then 7 potential scenarios:

- **Autonomous on-orbit assembly and payload refurbishment for large constellation in LEO.** This scenario aims at assembling and refurbishing OneWeb-like constellation satellites in LEO from 2D kits stacked in the launcher. In addition to cost savings from launch and mass optimisation, this scenario enables the accommodation of larger P/L on the P/F.
- **On-orbit Assembly and Refurbishment of a prepared multi-payload Satellite (LEO train).** This scenario aims at enabling a new rental business model where a platform (in LEO) would provide payload location (up to 80 P/L) with coarse pointing, power (up to 20 kW), data and mechanical I/F. This scenario is also an enabler to science missions (e.g. interferometry) requiring high space and time correlation that are not always possible with formation flying.
- **Large antenna manufacturing/assembly and payload refurbishment of GEO satcom or GEO Hub.** This scenario aims at manufacturing or assembling either large antennas (>8 m) on a GEO satcoms either a GEO Hub and providing refurbishment services over the satcom lifetime (mission reconfiguration P/L exchange …).
- **In-Orbit Cloud Spacecraft Assembly and Refurbishment.** This scenario aims at assembling on-orbit a fleet of "Cloud" spacecraft in GEO orbit to limit on-ground stations needs and improve bandwidth usage (feeder to ground). These Cloud Spacecraft are designed to be up-scaled to adapt to the growing demand and to take benefit from new technologies; as a long term asset, they would be regularly refurbished for maintenance and capacity upgrade
- **Large telescope in-orbit assembly and refurbishment.** This scenario aims at assembling a 10m space telescope, to be set-up to GEO and then service it during its whole lifetime. This large infrastructure is a sustainable long-term space asset that can evolve and improve its performance.
- **OSS for telecommunication GEO S/C or constellation.** This scenario aims at leveraging reflector antenna manufacturing and assembly as well as payload servicing capability to serve various telecommunication missions and constellation use cases: Constellations (scenario A) and GEO S/C (scenario C)
- **Long term space assets manufacturing and servicing**. This scenario aims at leveraging large structure and appendages manufacturing and assembly as well as platform servicing capabilities to support long-term space assets: Leo train (scenario B) and "Cloud" spacecraft fleet (scenario D)

All scenario were compared through a similar analyses based on CONOPS and capability assessment. Finally an assessment based on the 5 following criteria has been proposed: Technology complexity, Market trend, Timeframe, Business impact and Sustainability impact.

As a result, the two scenarios retained for the following steps of the study are:

- **Scenario A: OSS for LEO constellation manufacturing and servicing**
- **Scenario H: versatile OSS for Geo S/C, from telecommunication GeoHub to Cloud S/C**, resulting from the combination of Scenario C enriched with the concept of GeoHub (ie incrementally manufacturing large Geo space asset as for the LeoTrain) and Scenario D

3 SCENARIO DOWN-SELECTION

From a functional point of view, the two scenarios A and H are identical. The differences between them can be summarised in two key points:

Difference in Customer S/C distribution:

- Whereas Scenario A satellites are distributed across multiple LEO orbits with different RAAN and inclinations, requiring either multiple OSSs and/or large propellant loads and time to move between satellites, Scenario H satellites are all confined to a single orbit: GEO. For a minimal cost in terms of delta-V, the OSS can reach any position and therefore any satellite in this orbit. Disposal of waste material and resupply vehicles is similarly very cheap in terms of propellant cost.
- On the other hand, the cost to reach GEO is much higher than reaching LEO, both from a launch vehicle performance point of view and a spacecraft propellant need to transfer from the injection orbit to GEO. The second aspect can be mitigated by using a high-Isp propulsion system, but at the expense of much longer time to perform the transfer.

Difference in Customer S/C value:

- Scenario A satellites are typically small satellites with small unit cost. The value of the constellation is in the number of satellites. This makes refurbishing these small satellites a losing proposition compared to simply launching new ones, especially in light of the costs induced by the first point.
- On the other hand, Scenario H satellites are large and expensive because of the combination of:
    - Distance from Earth, which create high free space losses and therefore require high transmit power, large reflectors, or both
    - Cost to GEO (see first point), which creates an incentive for increasing the payload mass fraction of the satellite and its mission life. The long (typically 15 years) mission life also provides an incentive to upgrade the satellite at some point to adapt to changing markets.
    - Scarcity of longitude slots combined with demand for ever higher bandwidth, which results in operators packing ever higher throughput on a single satellite

Both differences have a dramatic effect on the in-orbit servicing and manufacturing value proposition and work against Scenario A.

Although both scenarios are technically feasible, the business case for Scenario A is weak at best, and with the arrival of very large constellations with decreasing unit cost and increasing ISMA cost, it becomes even weaker.

On the other hand, several use cases have been identified for Scenario H (GeoHub and Cloud S/C) which leverage trends in communication and data management on the ground.

4 PRELIMINARY MISSION DESIGN

Scenario H was expanded into a preliminary design of the space assets required to perform in-orbit manufacturing, testing and integration of large equipment for Customer satellites in geostationary orbit.

A specific use case was selected for this analysis, based on the choice of items to manufacture in orbit: a large telecommunication satellite is launched with most of its solar arrays, radiators and reflectors missing, taking advantage of the mass saving to increase the payload power and capability. The missing items are manufactured in near-geostationary orbit by Main Station from raw materials delivered by the Resupply S/C.

One counter-intuitive observation from this preliminary design is that the launch mass of the Main Station (~3800 kg) is considerably smaller than that of the Resupply S/C (~7200 kg). This is due to two factors: the large cargo mass (2300 kg) required to fully service two Customers as per the use case described above, and the decision to select a high-thrust bipropellant propulsion system to shorten the transfer time from GTO to GEO.

The proposed design offers a highly modular and flexible storage concept, allowing vastly different types of raw materials, pre-processed items, complete electronic equipment, tools and spares to be packaged in the same standard volume. A storage item may also use multiple standard storage volumes if needed, but that is exceptional. This design can also provide integrated electrical, mechanical and thermal interfaces for active equipment, and even allows daisy-chaining for ease of installation. Its size makes it easy to manipulate on the ground.

The number of different tools is kept to a minimum, with at least two reused across different items.

No particular challenge has been identified in the platform subsystems: there is scope for significant reuse of mature geostationary satellite technologies, processes and operations.

Aspects that would benefit from further investigation are detailed manufacturing processes and timeline analysis, and tool design, including mass and power needs.

5 TECHNOLOGY GAP AND DEVELOPMENT PLAN

The technology roadmap constitutes a reasonable plan for developing what is a very complex and challenging mission with multiple technologies never tried in orbit yet.

What emerges is a clear distinction between:

- On the one hand, platform and support technologies which are either based on extensive heritage (platform equipment) or require moderate evolutions based on existing technologies (PPS positioner, robotics, rendezvous, cargo). These technologies can be developed with a relatively low risk/good confidence in the outcome, duration and cost.
- On the other hand, in-orbit manufacturing technologies (materials and processes) which are still in their infancy and considerable uncertainty surrounds their feasibility. In particular:
    - Additive manufacturing of metals exhibits multiple challenges:
        - Powder-based ALM does not work well in micro-gravity,
        - Powder- and wire-based ALM generate fumes, not compatible with the required open workspace concept for continuous manufacturing,
        - Aluminium ALM cannot reach the strength of cast alloys; possible solutions are very low TRL.
    - Liquid glues suffer from outgassing and all glues require long curing times. The latter is the main driver for manufacturing the reflector and boom.

It is therefore recommended to focus on these specific technologies and mature them before revisiting the feasibility of manufacturing specific items in orbit, and only then consider launching the development of the support technologies.

END OF DOCUMENT