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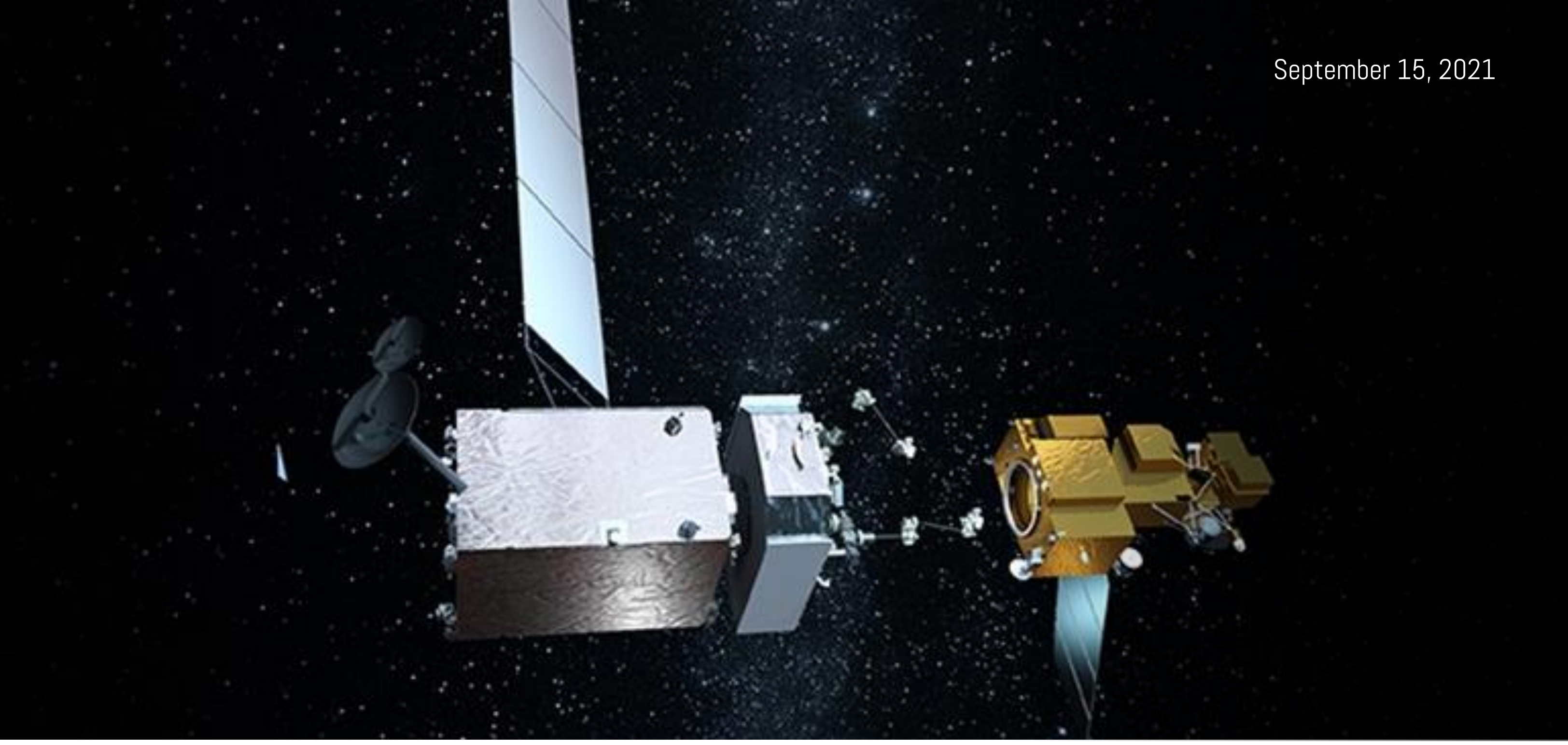

Photo by: National Aeronautics and Space Administration

On-Orbit Servicing

Opportunities for U.S. Military Satellite Resiliency

BY Hannah Duke

Satellites endure the harsh environment of space almost completely on their own. If something goes wrong, it is extremely difficult to physically access a satellite once it is in orbit. It has been this way since the first satellite was launched in 1957. Imagine the air conditioning in a house breaks, but you cannot fix it. So instead, you must abandon the house and buy a new one. Or imagine that every time a car runs out of gas, you take it to the junkyard and then buy a new car. This is how satellites are treated on-orbit. When satellites run out of propellant, they are deorbited or retired to a graveyard orbit. Or if something breaks—say, a solar panel fails to deploy—millions or even billions of dollars could be lost over a potentially simple mechanical anomaly.

Military satellites launched to geostationary orbit (GEO) can cost over a billion dollars.[1] On Earth, multimillion-dollar military assets do not sit untended; they are periodically serviced and upgraded over time. As competition in space rises, satellite owners and operators need to start thinking about how servicing capabilities used on Earth can be extrapolated for use in space. This involves developing robust on-orbit servicing capabilities as well as making space assets serviceable in the future.

"There is nowhere on Earth where we spend a billion dollars on a system and then never inspect it, and never maintain it, and never upgrade it."

– Dr. Gordon Roesler, former DARPA RSGS program manager

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The term on-orbit servicing (OOS) encompasses a set of emerging capabilities that provide access to satellites after launch, which could potentially revolutionize logistics and resiliency in space. For example, being able to upgrade sensors or add capabilities every few years, maneuver without regret, and inspect and repair satellites will cause a shift in the way satellites are designed, launched, and operated. Though OOS poses many benefits for the commercial space industry, this paper will focus on the benefits that OOS can provide the Department of Defense (DoD) and military-centric operations in space.

What is on-orbit servicing (OOS)?

Typically, discussions about spacecraft servicing are included in a larger grouping called on-orbit servicing, assembly, and manufacturing (OSAM). This grouping is broad and covers everything from repairing spacecraft to assembling space stations to 3D printing in space. While these capabilities are related to each other, this paper will focus solely on on-orbit servicing (OOS) and how it enhances logistics and resiliency of DoD operations in space.

OOS is defined as the observation or alteration of a satellite after initial launch by another spacecraft, also referred to as the servicing vehicle.[2] OOS encompasses inspecting, refueling, repairing, relocating, or upgrading a satellite while in orbit. For example, a servicing vehicle can extend the lifetime of a satellite by conducting a maintenance repair, taking over stationkeeping and maneuver functions, or transferring propellant.

The concept of servicing a spacecraft on-orbit is not new; NASA has been doing it for decades. NASA astronauts have serviced the Hubble Space Telescope numerous times and service the International Space Station routinely. Without the ability to repair or replace parts, these spacecraft would not have lasted as long as they have. However, NASA's servicing missions usually involve humans, which is not ideal for servicing satellites in orbits as high as GEO. For OOS to become a robust capability for the DoD, it needs to utilize autonomous robotic technologies.

The Defense Advanced Research Projects Agency (DARPA) demonstrated robotic refueling capabilities in 2007 with its Orbital Express program.[3] Since then, SpaceLogistics LLC, a subsidiary of Northrop Grumman, has successfully demonstrated OOS capabilities in GEO on two commercial missions, MEV-1 in 2020 and MEV-2 in 2021.[4] The Mission Extension Vehicle (MEV) docks to a client and uses the MEV's thrusters to extend the lifetime of the client satellite.[5] In this piggyback manner, when the client satellite runs out of fuel, the MEV uses its fuel to keep the client operational for up to five more years.[6] DARPA has another program called Robotic Servicing of Geosynchronous Satellites (RSGS), which has been developing robotic arms capable of repair, upgrade installation, inspection, and relocation.[7] RSGS is scheduled to launch these robotic arms on SpaceLogistics' Mission Robotic Vehicle (MRV) satellite bus in 2024.[8]

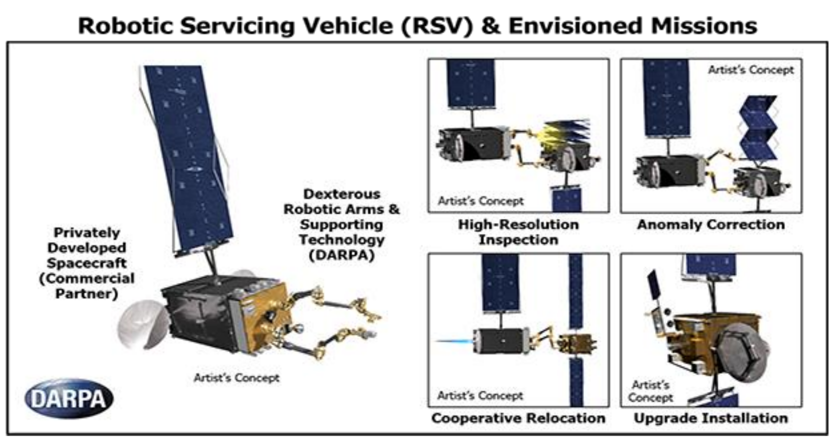

Figure 1: DARPA Robotic Servicing of Geosynchronous Satellites (RSGS)

How does OOS fit into DoD's space strategy?

Satellites are essential to modern military operations. These space assets support ground operations by providing superior communications; missile warning; position, navigation, and timing (PNT) capabilities; and sensing of key areas on Earth.[9] Particularly in GEO, these satellites can be multimillion-dollar assets that take up to a decade to develop, so it is important to be able to protect and maintain them.[10]

On-orbit servicing enables technology upgrades, repairs, and inspection of these satellites so that they can be maintained and kept in service for longer. OOS also enables the ability to maneuver these satellites without regret and can help speed up acquisition timelines. Each of these capabilities enhances logistics and resiliency in space. The 2020 Space Force Capstone Publication, *Spacepower*, highlighted space mobility and logistics (SML) as one of five core competencies of military spacepower.[11] As Space Force doctrine defines it, SML "enables movement and support of military equipment and personnel in the space domain."[12] The publication describes orbital sustainment as an important application of SML. Orbital sustainment involves the ability to "replenish consumables and expendables on spacecraft" and enables "spacecraft inspection, anomaly resolution, hardware maintenance, and technology upgrades."[13] These orbital sustainment activities can be accomplished through on-orbit servicing.

Developing robust OOS capabilities is integral to maintaining superior SML in space. According to the Space Force, SML is relatively uncontested right now, but as U.S. competitors continue investing in space capabilities, this may change.[14] Other countries with robust space programs, such as Russia and China, have demonstrated sophisticated on-orbit capabilities such as rendezvous and proximity operations (RPOs) with inspection satellites.[15] For example, a Chinese inspector satellite, Shijian-17, has a robotic arm and has performed a variety of orbital maneuvers in GEO to approach other Chinese satellites.[16] [17] This could be a reflection of an investment in OOS-related capabilities or it could be related to developing counterspace capabilities. It can be hard to determine the intent of these types of capabilities. Regardless, as other countries continue developing OOS capabilities, either for SML or counterspace purposes, it is important for the DoD to consider how OOS can enhance logistics and resiliency in U.S. military space operations.

"No nation has maintained a dominant position in a domain (air, land, maritime, space, and cyber) without a superior capability for movement and sustainment within that domain."

- 2020 State of the Space Industrial Base Report

OOS Benefits for DoD

On-orbit servicing (OOS) contributes to greater satellite resiliency by enabling the ability to upgrade, refuel, repair, and inspect satellites. OOS can also help mitigate orbital debris. Each section below will explore how these capabilities can benefit DoD operations in space.

Upgrade

Due to lengthy development timelines and longer lifespans of satellites in GEO, it can be difficult to keep those satellites up to date. However, this is critical to maintaining superior space operations. OOS can help address this by providing a means to upgrade satellite technology components on-orbit at a lower cost than building and launching an entirely new satellite. A servicer spacecraft can dock with a satellite and attach modules with new sensors, communications systems, or replacements for failed parts, similar to how certain hardware components in computers can be replaced. Updating sensors or other components every few years would help bolster a satellite's defenses and better protect classified data. For example, a client satellite could receive a new defensive payload that upgrades its jamming capabilities or an encryption hardware upgrade that strengthens its communications systems.

Modular payloads can add new capabilities to satellites relatively quickly because these modules can be developed and launched on their own timelines. The benefit of a module is that it does not have to be integrated into a satellite bus prior to launch; a servicing vehicle can simply attach a module to the client satellite already in orbit. This helps lower mission costs and speed up the timeline for developing, launching, and integrating new capabilities with existing military satellites. As the space domain becomes more contested, a modular upgrade process can help the DoD respond more quickly and efficiently to threats. It also keeps an adversary guessing a satellite's capabilities if they are being upgraded or changed over time.

An example of where this capability could be useful is with the Advanced Extremely High Frequency (AEHF) program, a jam-resistant military communications constellation that is being replaced by the next-generation Evolved Strategic Satellite Communications (ESS) program and the Protected Tactical SATCOM (PTS) system.[18] The ability to attach a module with new capabilities from the ESS or PTS program to an existing AEHF satellite could help with the transition between these systems.[19] If AEHF had been designed to support modular upgrades, the existing constellation could have been updated and built upon instead of being fully replaced, which could have saved billions of taxpayer dollars. This concept is similar to the Navy's EA-18G Growler aircraft, which is being equipped with an external Next Generation Jammer pod to upgrade electronic warfare capabilities instead of replacing the entire aircraft.[20]

DARPA's RSGS program hopes to demonstrate robotic installation of new payloads carrying upgrades.[21] For now, these attachable payloads would need their own means of power and communication since most host satellites are not designed to support upgrades. However, future satellites can include interfaces that enable data and power transfers.[22] It will be important to make these interfaces standardized across industry, similar to a USB port on a computer. As technology continues to improve rapidly, OOS provides a way to match the evolving technology pace and keep critical military satellites secure and technologically sophisticated.

Refuel

The amount of on-board propellant can ultimately determine the lifespan of a satellite. Without propellant, a satellite has no way to maintain its position and orientation in orbit (called stationkeeping), so it must be deorbited or retired to a graveyard orbit.[23] Since solar power usually powers a satellite's onboard computers and sensors, a satellite may still be operational after running out of propellant. However, without the ability to stationkeep, the satellite cannot continue fulfilling its mission objectives.

If satellites could be refueled by a servicing vehicle, it could extend the satellite's lifetime potentially by years. A servicing vehicle can refuel a client by transferring propellant. This is similar to what SpaceLogistics did in 2020 and 2021 for two Intelsat satellites. However, the MEV doesn't refuel client satellites directly; it docks with the client and uses its own fuel to extend the client's lifetime.[24] This "piggyback" life extension service is currently enabling two Intelsat satellites to provide communications for up to five more years.[25] This was an important demonstration because it proved that servicing capabilities are viable for clients that were not originally designed to be serviced.

A similar upcoming mission is NASA's On-orbit Servicing, Assembly, and Manufacturing (OSAM) 1, which plans to demonstrate robotic refueling services in low-Earth orbit (LEO) for a U.S. government satellite, Landsat 7, that was not designed to be refueled.[26] The OOS spacecraft bus is designed by Maxar Technologies and will support a NASA Goddard payload of two robotic arms that will grab, refuel, and relocate the client satellite.[27] This demonstration is an important proof of concept because, unlike MEV's piggyback life extension, OSAM-1 aims to directly refuel the client satellite. Without standardized grapple fixtures, it is difficult to service a satellite already in orbit. These missions are helping shape standards for servicing and rendezvous and proximity operations (RPOs). The NASA mission will also include another payload by Maxar called the Space Infrastructure Dexterous Robot (SPIDER), a robotic arm that will demonstrate on-orbit assembly and manufacturing.[28]

Being able to directly refuel a satellite or use a piggyback life extension service enables an expanded satellite architecture as older satellites are kept in operation for longer. If a satellite in a graveyard orbit is still functional, a servicing vehicle can bring it back to operational orbit, similar to what MEV did for Intelsat 901.[29] In a conflict, this could potentially add surprise redundancy as OOS vehicles retrieve or refuel decommissioned satellites, returning them to full operation.

Even before a satellite is retired, refueling could give a satellite enough extra fuel to relocate to a new location within an orbit. This could be useful for strategic or defensive purposes. For example, during the Gulf War, military satellites were maneuvered so that more GPS satellites passed over the Persian Gulf to increase global positioning system (GPS) availability in that area.[30] Alternatively, if a satellite is in a vulnerable position, it can perform a defensive maneuver and change its location within an orbit. To make these maneuvers, satellites must expend fuel, which reduces the overall lifespan of a satellite. However, with a refueling capability, an operator can maneuver a satellite without sacrificing the overall lifespan of the satellite. This is known as “maneuvering without regret” and is key to superior SML.

Finally, launching all the fuel a satellite will need for its entire lifetime at once adds greatly to the mission weight, which limits available launch options, and cost. Being able to refuel on-orbit means that satellites could launch with less propellant, thus reducing launch cost and weight so that more launch providers could be used. This is similar to how some military planes takeoff without a full load of fuel so they can carry more payload, and once they are at altitude, they refuel. Ideally, future spacecraft will have standardized fuel valves so that they can be easily refueled by a servicing vehicle.

Repair

The ability to repair space assets is an important aspect of satellite resiliency. Currently, if a military satellite’s antenna breaks or a solar panel doesn’t deploy correctly, the entire mission could fail, resulting in the loss of hundreds of millions of taxpayer dollars. In some cases, less than a pound of force may be necessary to fix mechanical problems, but because it is currently infeasible to physically access satellites on-orbit, a simple mechanical anomaly can be devastating.[31] OOS provides that physical access to space assets that is currently lacking. Another feature of DARPA’s RSGS program is the development of robotic arms to demonstrate that robotic repairs on-orbit are feasible and can be a key tool in increasing satellite resiliency.

Inspect

OOS vehicles can use cameras for imaging a satellite up close or from a distance. These images provide an additional way to inspect satellites on-orbit. If a satellite experiences an anomaly, an external inspection can identify the issue and help operators with anomaly resolution. Inspection is also an important precursor to any repair or upgrade operation. Since a servicing vehicle needs to attach to a client to perform a repair or attach a module, it’s crucial to thoroughly inspect the client before attempting an RPO. For example, SpaceLogistics’ MEV vehicles used cameras, onboard computers, and laser rangefinders to thoroughly inspect Intelsat’s satellites before docking.[32] Without thorough inspection capabilities, the two spacecraft could be in danger of colliding and damaging or destroying both spacecraft in the docking attempt.

Inspection capabilities also increase in-situ space situational awareness (SSA). The ability to inspect other satellites by taking images from space is an important deterrence capability because it makes the space domain more transparent. In-situ inspection allows for a more detailed characterization of space objects that might not be possible with ground-based sensors.[33] Inspection also allows a user to track behaviors in space and better determine their purpose. For example, on-orbit inspection can help determine whether anomalous satellite maneuvers are due to nefarious activities or simply avoiding a piece of space debris. Inspection is currently being used to gain more situational awareness about other nations' satellites. For example, the U.S. Geosynchronous Space Situational Awareness Program (GSSAP) includes multiple satellites in the near-GEO region that can inspect other space objects and perform RPOs.[34] The GSSAP program could utilize servicing satellites as part of its inspection constellation to increase redundancy and coverage of the GEO belt.

Debris Mitigation

Part of maintaining superior SML is ensuring the environment remains sustainable. GEO is a high-value orbit for military activity, but it is also a limited resource. Similarly, high-value LEO orbits are getting more crowded, and the risk of debris colliding with an operational spacecraft is rising. In all operating orbits, the DoD should consider how OOS can aid in keeping the space domain sustainable. OOS can help extend a satellite's life through refueling or upgrading so that less proliferation of space assets is needed. Once a satellite reaches its end of life (EOL), OOS vehicles can deorbit or relocate a satellite to a graveyard orbit. OOS can also help declutter orbits by grappling and relocating existing orbital debris. Private company missions like the recently launched End-of-Life Services by Astroscale demonstration (ELSA-d), are developing servicing technologies for life extension, EOL, and debris mitigation.[35]

Figure 2: Objects in Space. Credit: European Space Agency

In July 2021, the Secretary of Defense released a memo outlining tenets of responsible military behavior in space.[36] One of the tenets is to "limit the generation of long-lived debris."[37] A way to make sure that debris is not "long-lived" is to actively remove it through OOS. The DoD helps set international norms of behavior in space through example, and debris mitigation should continue being a priority to keep the space domain sustainable for future military, civilian, and commercial activity.

Challenges & Recommendations

The Chicken and the Egg

As OOS capabilities continue to emerge, it will be important for the DoD to clearly communicate its needs to industry. If commercial companies do not see a demand for OOS, then there is little incentive to develop or continue investing in these capabilities. However, if there are not commercially available servicing capabilities, then government stakeholders may not see a need to make their satellites serviceable. This is a classic chicken and egg problem.[38] The DoD can help solve this dilemma by continuing to invest in programs like DARPA's RSGS, which helps further demonstrate the technological feasibility of robotic on-orbit servicing. RSGS's partnership with SpaceLogistics also helps assure the commercial sector that the DoD is interested in investing time and resources into these services. By sharing case studies and specific DoD needs for servicing, commercial companies will have more guidance for which servicing technologies should receive priority investment.

Another key step the DoD can take to support the emerging servicing industry is to design future satellites to be serviceable. For example, military satellites can include standardized grapple fixtures, refueling valves, and interfaces for connecting modular payloads to satellite buses. NASA recently partnered with three commercial companies, Altius Space Machines, Honeybee Robotics, and Orbit Fab, to start developing and testing various autonomous, robotic grapple fixtures.[39] Additionally, DARPA runs the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) which aims to develop technical and safety standards for a reliable and responsible OOS industry.[40] DARPA is transitioning CONFERS leadership over to industry so that the commercial sector has more say in shaping these standards. Having standardized components and procedures for RPO will help boost investors' confidence in this emerging industry.

Policy Challenges

In order for the servicing industry to thrive, regulation and liability issues should be addressed. For example, OOS vehicles typically have to ask the federal government to share spectrum.[41] GEO is particularly difficult because the International Telecommunication Union (ITU) only allocates spectrum by orbital slot, but servicing vehicles will need to travel through multiple slots to serve multiple customers.[42] Ideally, servicing vehicles could have their own spectrum allocation that allows them to access spectrum across multiple orbital slots.

Another regulatory challenge involves remote sensing licenses. Since servicing satellites use cameras for inspecting client satellites, they need remote sensing licenses even if their intention is not to take images of Earth.[43] Obtaining these licenses is a lengthy process because it goes through national security review.[44] The first step in addressing these regulatory obstacles is having the federal government outline high-level policy priorities for servicing. From there, separate regulations could be created specifically for the OOS industry so that it does not have to go through as many bureaucratic hoops.

Additionally, the liability involved in these operations may be a challenge. The International Space Station (ISS) sets some precedent for multilateral servicing agreements, but a robust OOS industry will need more thorough liability procedures. For example, if two parties interested in a servicing partnership agree to waive liability, what happens if an uninvolved third party is somehow affected? Nations are ultimately liable for private citizen activity in space, so commercial companies can potentially be limited in their operations if their respective governments do not approve of their plans.[45]

Conclusion

OOS capabilities can enhance military operations in space by enabling mobility and logistics and increasing resiliency and redundancy of satellite systems. Being able to upgrade, refuel, relocate, repair, and inspect satellites on-orbit can revolutionize the way the DoD operates in the space domain. OOS can also help enable the ability to maneuver satellites without regret and mitigate orbital debris. DoD investment in programs like RSGS reflects an interest in developing these capabilities. Companies like SpaceLogistics are already demonstrating satellite mission extension services that can greatly increase military satellite resiliency and redundancy. As other countries with robust space programs pursue sophisticated OOS capabilities, it will be integral for the DoD to incorporate these services into its space operations. By stating clear needs, setting policy priorities, and addressing the regulatory challenges involved, the DoD can help bolster commercial investment in OOS. As the space domain becomes more contested, it is important to embrace emerging capabilities like on-orbit servicing that can help maintain superior DoD operations in space. ›

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Acronyms

CONFERS – Consortium for Execution of Rendezvous and Servicing Operations

DARPA – Defense Advanced Research Projects Agency

DoD – Department of Defense

ELSA-d – End-of-Life Services by Astroscale demonstration

EOL – End of life

GEO – Geostationary orbit

GSSAP – Geosynchronous Space Situational Awareness Program

ISS – International Space Station

ITU – International Telecommunication Union

LEO – Low-Earth orbit

MEV – Mission Extension Vehicle

NASA – National Aeronautics and Space Administration

OOS – On-orbit servicing

OSAM – On-orbit servicing, assembly, and manufacturing

RPO – Rendezvous and proximity operations

RSGS – Robotic Servicing of Geosynchronous Satellites

SPIDER – Space Infrastructure Dexterous Robot

SSA – Space situational awareness

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