Commercial and Civil Robotic Rendezvous and Proximity Operations

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Summary

Over the past two decades, several countries have begun developing rendezvous and proximity (RPO) technologies for non-military purposes such as satellite inspection, refueling, repairs, on-orbit assembly, and debris removal. In addition to government-funded programs, companies have also begun developing, testing, and operationalizing capabilities to provide commercial on orbit satellite servicing capabilities such as life extension, repair, refueling, and inspection. In January 2020, the first commercial satellite servicing mission successfully docked with and repositioned a commercial communications satellite in the geosynchronous region. In early 2022, China successfully removed a dead satellite from GEO to the graveyard region. Several additional commercial/civil demonstrations and operational missions are planned over the next few years.

RPO and On Orbit Servicing (OOS)

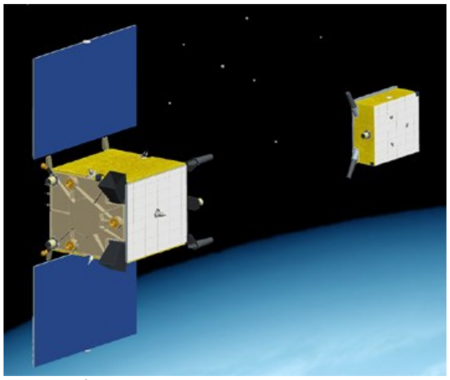
Proximity operations are a series of orbital maneuvers executed to place and maintain a spacecraft in the vicinity of another space object on a relative planned path for a specific time duration to accomplish mission objectives. Rendezvous is a process wherein two space objects (artificial or natural body) are intentionally brought close together through a series of orbital maneuvers at a planned time and place. Taken together, RPO technologies enable a wide range of capabilities to support civil and commercial on-orbit satellite servicing (OOS) capabilities such as inspection, repair, refueling, assembly, and life extension. RPO capabilities can also be used for military and intelligence space activities such as intelligence, surveillance, and offensive weapons such as co-orbital anti-satellites.[1]

Civil Robotic RPO and OOS Technology Development and Testing

While RPO capabilities have a long history in human spaceflight, the past twenty years have shown a growing focus on developing robotic versions of these same capabilities. This focus includes government funding to conduct research and development of underlying technologies, technology transfer to industry, and industry efforts to commercialize the technology and identify customers.[2]

The first robotic RPO mission to be categorized as a civil operation was the November 1997 Japan ORIHIME and HIKOBOSHI test conducted by the Japan Aerospace Exploration Agency (JAXA). As part of the Engineering Test Satellite VII, the servicer satellite (Orihime) orbited the client satellite (Hikoboshi) and became the first successful instance of autonomous robotic rendezvous and docking with another space object.[3] While orbiting, Orihime took pictures, inspecting Hikoboshi before redocking and finishing the autonomous test.

On April 14, 2005, NASA launched the DART satellite to conduct an autonomous rendezvous experiment with a U.S. Navy communications satellite, MUBLCOM.[4] DART ended up "bumping" into MUBLCOM during the test but both satellites were unharmed. An after-action report concluded that the incident was due to a malfunction of the automated rendezvous system, although not all details were released due to export control and classification restrictions.



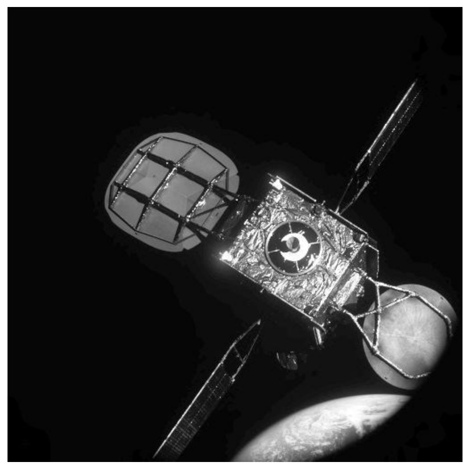
Prisma's Mango & Tango. Image credit: European Space Agency

In 2010, Sweden began an RPO mission of their own focusing on autonomous guidance and navigation experiments.[5] The pair of satellites in the PRISMA mission, PRISMA Target and Main, were also commonly known as Mango and Tango. This close-approach experiment also provided GPS navigation testing for future formation flying as well as other technology experiments for various European partners.

January 2016 marked the first university-led test of RPO capabilities. BEVO-2 and AggieSat4 were part of the second LONESTAR mission aimed at testing in-space navigation capabilities built and conducted by the University of Texas and Texas A&M.[6] BEVO-2 was deployed from AggieSat4 after both were released from the ISS. The pair of satellites proceeded to practice communication and data exchange while station-keeping and updating their navigation. This marked a key capability to remotely conduct accurate communication transfer and flying controls with navigation and guidance techniques.

As part of their program to develop OOS capabilities to support future missions, NASA has two missions focused on On-orbit Servicing, Assembly, and Manufacturing (OSAM), dubbed OSAM-1 and OSAM-2. OSAM-1's primary mission is to demonstrate the ability to refuel a satellite, but also includes a robotic arm known as SPIDER that will demonstrate the ability to assemble an antenna in space.[7] OSAM-2 involves a satellite called Archinaut One that will build, assemble, and deploy its own operational solar array.[8]

Other commercial and civil RPO developments include Italy's D-Orbit ION launched in September 2020, which offered rideshare opportunities to bring satellites to their operational orbits faster than typical drifting procedures.[9] Additionally, Japanese start-up Astroscale's ELSA-d servicer launched in March 2021 and successfully demonstrated the ability to rendezvous, inspect, and capture another object to support future active debris removal missions.[10] The Swiss company ClearSpace also has a contract from the European Space Agency to remove a 100-kg upper stage adapter from orbit in 2025.[11]



View of IS-901 from MEV-1 while docking. Image credit: Northrop Grumman.

On October 24, 2021, China launched the SJ-21 satellite for a space debris mitigationmission.[12] On December 25, 2021, the SJ-21 rendezvoused with the Compass G2, a defunct Chinese navigation satellite. The Compass G2 had experienced a fragmentation event in 2016 which released six traceable pieces.[13] The SJ-21 docked at some point and on January 21, 2022, used its onboard propulsion to pull the Compass G2 to a higher altitude above the geostationary belt.[14]

There have also been two commercial satellite servicing missions. The Mission Extension Vehicle 1 (MEV-1), a satellite developed by SpaceLogistics (a subsidiary of Northrop Grumman), docked with the Intelsat 901 (IS-901) satellite in March 2020 just above the geostationary belt to provide life-extension and repositioning services through 2025.[15] MEV-2 launched in August 2020 and docked with Intelsat 10-02 in April 2021 in the geostationary belt to begin a similar five-year life extension mission.[16]

While there have only been a few commercial missions to date, the advances in technology, changes in national policy, and new regulations could spark a significant increase in the future. In the past year, multiple start-ups have emerged offering their first clients satellite servicing, active debris removal, and end-of-life services; this indicates a promising future for the commercial space industry. The Consortium for Execution of Rendezvous and Servicing Operations (CONFERS), created in 2017 with initial funding from the Defense Advanced Research Projects Agency (DARPA), today has more than 50 members from several countries planning a wide range of future commercial OOS missions.[17]

Dual Use and Transparency

The growing advances in commercial and civil RPO and OOS capabilities raise important questions about the distinction between their activities and RPO conducted for military or intelligence reasons. Increased transparency is needed, along with the establishment of norms of behavior and technical standards, to increase the safety of commercial and civil RPO and OOS and help distinguish them from military and intelligence activities.

Summary of Known Commercial and Civil RPO & OOS Activities in Space

Country	Date of Activity	Servicer Satellite	Client Satellite	Launch Site	Notes
Japan	Nov. 1997	ORIHIME	HIKOBOSHI	Tanegashima Space Center	Demonstrated autonomous docking and satellite servicing with onboard mounted robotic system
USA	April 14 2005	MUBLCOM	DART	Vandenberg AFB	NASA DART bumped into military satellite during proximity test, unclear if offensive test
Sweden	Aug. 2010 - July 2011	PRISMA Target	PRISMA Main	Dombarovskiy Air Base	Demonstrated autonomous guidance and navigation experiments
USA	Jan. 2016	BEVO-2	AggiesSat4	Cape Canaveral	Pair of satellites deployed from ISS to practice station keeping and navigation
USA	Jan. 25 2020—present	Intelsat 901	MEV-1	Baikonur	MEV-1 successfully docked to provide mission extension services for Intelsat 901
USA	June 15-29 2020	Aerocube 10-A	Aerocube 10-B	Wallops	AC-10B entered a proximity orbit around AC-10A and used its on-board camera to take resolved images of AC-10A.
Italy	Sept. 3 - Oct 28 2020	D-Orbit ION	Multiple	Guiana Space Center	ION performed rendezvous operations with multiple satellites to bring it to its designated orbit faster than normal drifting
USA	April 12 2021—present	MEV-2	Intelsat 10-02	Guiana Space Center	MEV-2 successfully docked with Intelsat 10-02 to provide mission extension services
China	April 27, 2021 (launch)	NEO-1[18]	?	Taiyuan Satellite Launch Center	NEO-1 planned to release a small piece of pseudo-debris and then capture it again using a net system. Mission status is unknown
Japan	March 2021—May 2022	ELSA-D Servicer	ELSA-D Client	Baikonur	ELSA-D magnetically docked with the client sub satellite and demonstrated RPO stationkeeping and on-orbit inspection
China	Oct 2021—Jan. 2022	SJ-21	Compass G2	Xichang Satellite Launch Center	SJ-21 docked with Compass G2 and towed it to the GEO graveyard, before detaching and returning to active GEO region
USA	April 2023	LINUSS1	LINUSS2	Kennedy Space Center	One cubesat performed the role of a servicing vehicle to the other. The mission was used by Lockheed Martin to test various algorithms, SSA cameras, and the new ASPIN.

Endnotes

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