Refuelling a Sustainable Future in LEO – Introducing LOOP

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Abstract **- The rapidly growing space economy demands innovative solutions for in-orbit refuelling and servicing, space transport and other spacecraft-based operations to achieve sustainability, resilience, and scale of operations in space. With more intentional and focused sustainability guidelines on the horizon from the European Union (EU), and the impending EU space law, it is strategically important for operators to plan for enhanced compliance practices and incorporate refuelling abilities for their upcoming missions. Dawn Aerospace's Loop network is an in-orbit refuelling solution offering a comprehensive refuelling and servicing experience through a network of servicers and in-space propellant depots, and is intended to support satellite operators in the Low Earth Orbit (LEO) to adapt, evolve and extend their missions in space. This paper explains Dawn Aerospace's approach to building and operating the transformative Loop network, and offers guidance to satellite operators on the economic, technological, regulatory and strategic benefits of integrating the Loop network into their existing operation planning and upcoming missions.**

Index Terms – In-orbit refuelling, Space Sustainability, Satellites, Low Earth Orbit, Propulsion.

1. THE CASE FOR IN-ORBIT REFUELLING

In recent times, highly innovative satellites, space transportation solutions, and deep space exploration use cases have showcased the need for robust propulsion solutions for flexibility of operations in space. Various in-orbit servicing spacecrafts have appeared on the horizon to clean debris or maintain satellites, but they too anticipate an increased need for refuelling capabilities to scale their operations. Despite widespread agreement that in-space refuelling is required to scale space operations, satellites and spacecrafts are currently designed for carrying a finite supply of fuel, and over-engineered keeping in mind propellant use and requirements for the entire life of its mission and for post-mission disposal. Any unplanned scenarios, which are not uncommon in space, eat away at the operator's ability for realizing the satellite's utility and potential. This is particularly limiting for missions and business models that rely on constant relocation in orbit, or companies that provide a range of services and require flexibility in their operations in space.

As orbits in space become increasingly populated and difficult to navigate, maneuverability is an essential aspect of space operations. This combined with propellant planning for rapid deorbiting or pre-planned manoeuvres to graveyard orbits, and increasingly demanding regulatory requirements for space traffic management and sustainability, proper end of life disposal, fuel management and its impact on the overall compliance posture of the space system, is set to become all the more complex. In-orbit refuelling solutions changes the rules of the game by allowing satellites and spacecrafts to be refuelled in space, thereby extending their lifespans and aiding missions to be more flexible and cost-efficient, saving on the expense of building, launching and de-orbiting new satellites and spacecrafts. In-orbit refuelling services also impact the growing issue of orbital clutter, contributing to a cleaner and more sustainable space environment. Further, the ability to refuel satellites as needed, makes fuel an optional operational cost and significantly alters the operational limitations of propellant capacity. While a non-refuellable satellite or spacecraft has limited ability to manoeuvre, a refuellable system can elect to make as many manoeuvres or changes in positions as it makes financial sense for the operators to do so.

For significantly advancing space sectors such as the European space sector, which is guided by conscious guidelines on sustainability and innovation, in-orbit refuelling is quickly becoming a necessity for achieving sustainability, cost efficiency, competitiveness and compliance. Even if such solutions are available, the mechanisms of such a solution needs to be accessible to the market and available at scale. The need for in-orbit refuelling and accessibility of in-orbit refuelling services on one hand, and the availability of reliable in-orbit refuelling services on the other hand poses a 'chicken and egg' problem. Through this paper, Dawn presents its innovative Loop network, which provides a feasible solution to this impasse.

2. INCREASING REGULATORY SCRUTINY

This section outlines the increasingly complex regulatory landscape that space actors have to navigate. While regional and national space laws and industry frameworks are still maturing, they signal a clear shift toward a more structured and regulated orbital environment. Such a trend translates to increased regulatory scrutiny and compliance demands placed on satellite and spacecraft operators. It becomes all the more important for operators to work with proven systems that are already designed with emerging compliance in mind, and with partners with an established track record of understanding the legal and technical intricacies of the space sector.

2.1 International Frameworks. International frameworks such as the Outer Space Treaty (1967), Convention on Registration of Objects Launched in Outer Space (1967), the Liability Convention (1972), and the UN Guidelines for Long-term Sustainability of Outer Space (2019) have established the foundations for responsible behaviour towards sustainability in outer space.[1] These international frameworks alone are not substantial or sufficient to deal with the many foreseen problems in LEO.[2]

2.2 Regional Frameworks. Regional and national regulations and initiatives seek to build on the international commitments and offer more specific guidance to non-State space actors. For example, the European Space Agency has fostered global consensus on space sustainability through its ESA Zero Debris Charter which sets collective guiding principles and jointly defined targets that signatories strive towards.[3]

Through a distinct but related 'Zero Debris Approach' ESA intends to drive the industry towards the 2030 goal of becoming debris-neutral, and as a first step has outlined its debris mitigation requirements in an internal manual.[4]

The impending EU Space Law intends to shape a regional approach to space activities, including on sustainability. In fact, the Commission has already proposed a tentative space labels system (akin to the EU Ecolabels), to develop sustainability standards for EU-owned assets or EU Member States' assets delivering space services in the EU.[5] The space labels framework is likely to rely on lifecycle assessments and supply chain data to evaluate environmental performance.

On this front, the EU Commission for Defense Industry and Space (DG DEFIS) has initiated a Product Environmental Footprint Category Rules (PEFCR) development project, which aims to introduce a standardised approach for environmental impact assessments and reporting, and develop a consistent approach for the space sector.[6]

The European Union has indicated a growing consensus to develop stricter debris mitigation practices, and this forebodes an increasingly complex regulatory regime for both the EU space actors seeking to conduct space activities and external space actors and services providers targeting the EU market.[7]

2.3 National Regulations. National space laws are increasingly evolving to anticipate the rise of in-space servicing activities and emerging technologies such as rendezvous and proximity operations (RPO), satellite refuelling, and active debris removal.

For example, France, which has one of the most detailed and developed European space laws from 2008, and has regularly updated the law and technical standards under the law, with the most recent update being in 2024 with regard to standards for rendezvous and proximity operations in space.[8] In addition to requiring space objects to be designed to facilitate capture by service vehicles, operators who benefit from any in-orbit servicing (not just refuelling) are required to submit plans to CNES at least once a year, which report includes details of fuel expenditure and management.[9] Space systems are required to be designed and implemented with operational capabilities to manage risk manoeuvres and limit collision risks.[10] The French law also places several obligations on in-space services providers, including to qualify approaching, docking and undocking technologies,[11] which contributes to the regulatory compliance of the overall rendezvous and docking operations for provision of in-space services. This goes to show that for French space operators, working with partners who have demonstrated compliance with applicable EU laws, and with proven components is already an important aspect to demonstrate overall compliance to the regulator.

2.4 Industry Standards and Practices. In parallel, the commercial space industry has proactively moved to shape best practices. Organizations like the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) and Collaborations in Orbit for Space Maintenance, Inspection, and Consolidation of Standards (COSMICs) have developed non-binding but widely respected technical and safety standards, providing a roadmap for responsible and transparent conduct of rendezvous and proximity operations, and on-orbit servicing.

These industry-led efforts are complemented by international standards, notably the 'ISO 24330:2022 Space systems - Rendezvous and Proximity Operations (RPO) and On Orbit Servicing (OOS) - Programmatic principles and practices' standards outline the principles for rendezvous and proximity operations, and on-orbit servicing, and the 'ISO 24113:2023 Space systems - Space debris mitigation requirements' provides debris mitigation guidelines. It is notable that ISO 2411:2023 has been used as a mandatory requirement by many national licensing regimes in the EU for space activities, and is likely to become a default under the EU space law as well, as a matter of industry practice. [12]

3. THE 'LOOP' NETWORK

This section outlines the choices Dawn Aerospace has made for the Loop network, in order to deliver several strategic advantages for its customers.

3.1 Space Heritage and Flight-Proven Components. Dawn Aerospace is a green propulsion company with a range of turnkey satellite propulsion systems including thrusters, tanks, electronics and software. Dawn's space heritage includes 122 thrusters in space, equipped on 26 satellites and more with applications in LEO and MEO, ranging from earth observation and communications systems to orbital transfer vehicles, lunar missions and even deep-space mining. Dawn, with a vision to solve the 'chicken and egg' problem of in-space refuelling, has developed its groundbreaking Loop refuelling programme which is a scalable and sustainable model for in-orbit refuelling of satellites and spacecrafts alike.

3.2 The Loop network. Loop consists of space utility vehicles (SUVs) which carry propellants from orbital tankers parked at strategic orbits to customers' satellites or spacecrafts. The SUVs are equipped with prevision navigation and autonomous docking capabilities, ensuring secure and efficient servicing operations. At the customers' end, the integration of sophisticated docking technologies will enable the seamless transfer of fuel. These mechanisms are designed for high reliability and multiple reuses, and can accommodate a wide range of satellite designs.

The docking and fluid transport port (DFT port) consists of advanced ports for fluid transfer, for power and data, and a mechanical port for towing. The fluid port allows satellites to refuel in orbit, enabling longer missions and reducing the need to launch replacements. The power and data port takes flexibility a step further, allowing satellites to connect for cooperative operations. Meanwhile, the mechanical port opens up entirely new possibilities, enabling towing for orbital repositioning, and rescue operations for malfunctioning satellites. The DFT also serves as a critical contact point for debris removal operations, thereby solving for the safety and sustainability compliance requirements that are critical for space operators, particularly imminently for satellites operating in Low Earth Orbit.

The port setup consists of two parts: the passive side on the customer vehicle, and the active side on Dawn's SUV. On the customer's side, the DFT port replaces standard manual fill/drain valves used for propellant loading on the ground with a passive interface that can facilitate refueling in space, adding only 0.6 kg. It includes provision for two pressurized propellants, nitrous oxide, and propene or ethane, as well as power and data connections. Beginning 2025, Dawn's customers will be service-ready by default, as some of Dawn's customers already include the DFT port in their propulsion systems which are expected to be in-orbit by 2026.

3.3 Sustainable, Safe and Reliable Propulsion Choices. Dawn supports nitrous-based propulsion systems, as (i) no pumps are required for propellant transfer, and (ii) once a connection is established, propellant can be transferred by virtue of temperature differential alone. This is possible due to the self-pressurizing nature of the propellants.

Further, Dawn's systems do not require life-limiting catalysts. Nitrous thrusters, unlike hydrazine or hydrogen peroxide thrusters, are spark-ignited and thus theoretically capable of near-infinite restarts and propellant throughput. This allows systems to be refueled and reused nearly indefinitely, thereby contributing to sustainability of the propulsion solutions and also managing costs efficiently.

In contrast, traditional chemical propulsion systems employed on satellites based on Hydrazine require three fluids (an oxidizer, a fuel and a pressurant fluid) and a pressurizing system with high power requirements, and high complexity which lends itself to higher risk for in-space refuelling activities. Electric propulsion systems based on Xenon or Krypton also require complex pressuring systems, which translate to increased complexity and lower reliability as there is an additional dependency on the pressuring system.

Dawn has invested in its propulsion research from scratch, and its propulsion choices have been considered by NASA to be state-of-the-art technology for small satellites since 2020.[13] Dawn produces nitrous-based satellite propulsion for over 20 customers worldwide, and its green propulsion technology sets a new standard for environmentally responsible space activities, highlight the company's and Loop's commitment to reliability, safety and sustainability.

3.4 Strategic Advantages for Customers. Integrating the Loop network in mission planning offers several advantages to satellite and spacecraft operators:

(i) Enhanced ROI: Dawn's Loop network helps satellites achieve significantly longer operational periods, enhancing the return on investment and business cases for satellite operators through a gainshare model, allowing for ambitious mission profiles. For example, a typical LEO mission satellite costs between 5-20 million euros and is amortised over a 3-7 year mission lifetime. A single refuel will double the mission capability, resulting in longer utilization of a single asset. The ability to treat refuelling as an operating cost makes satellites reusable assets, and spacecrafts able to maximise their strategic value by adopting a number of missions from hauling cargo to lunar expeditions, as the case may be. The ability to launch with lesser fuel than required for the lifetime of the mission can also delivery cost efficiencies at launch.

(ii) Increased Resiliency: Traditionally, space missions are largely limited post-launch due to fuel constraints. In-orbit refuelling enables operators flexibility to repurpose or readjust mission objectives in a dynamic manner based on evolving ground or regulatory requirements, or even commercial opportunities.

(iii) Improved Compliance: Dawn Aerospace is a signatory to the ESA Zero Debris charter. Dawn's docking and refuelling port setup has been designed to be compatible with the international CONFERS and COSMICs standards. Dawn Aerospace actively participates in PEFCR working groups and other forums for development of regulations and standards for the space sector, and is invested in bettering the overall regulatory compliance and sustainability efforts of its customers.

For the European space sector, Dawn's Loop solution addresses the three pressing challenges of sustainability, cost-effectiveness, and EU resilience. It demonstrates how operators can flexibly adapt Loop to achieve enhanced compliance postures in preparation for upcoming regulatory requirements such as the EU space law. By maximising the potential of each satellite, Loop's multi-port connectivity ensures compliance with the EU's long-term sustainability focus while unlocking new commercial and operational opportunities. With this kind of adaptability, space actors will be able to increasingly leverage satellites as long-term assets for competitiveness in the space economy.

(iv) Focused Investments on Proven Technology: Dawn's DFT ports takes advantage of Dawn's existing flight-proven components such as valving common to the B20 thruster, of which over 200 units are already in space. The SUV subsystems build on Dawn's existing propulsion systems, proven in space environments. Dawn Aerospace has a proven and existing line of propulsion systems, space heritage and customer base. Dawn Aerospace is well positioned to provide in-space refuelling services

(v) Trusted Partner and Support: Dawn is a full-service partner, and collaborates with customers from initial design through on-orbit commissioning and operations to ensuring seamless integration and operation. Dawn's turn-key solutions cater to a wide array of satellite applications, including SmallSats, Orbital Transfer Vehicles, CubeSats and more. Dawn is vertically integrated and has its own production facilities and proven supplier networks catering for certifiable mission-grade products and worldwide regulation standards, which enables Dawn to act and solve problems faster and at lower costs for customers than traditional service providers. For example, Dawn has a heritage of investing in improving its products and one of its goals is to continue to optimize the docks for mass, with a view to deliver cost efficiencies to customers.

4. CONCLUSION

As the space economy accelerates, mission architects must recognise that achieving technical excellence of space systems is just one piece of the puzzle. The need for innovative, scalable technical solutions that also address non-technical factors such as sustainability, regulatory compliance and resilience are more critical than ever. In-orbit refuelling technologies, such as Dawn Aerospace's Loop network, represent a fundamental shift in how satellite and spacecraft operators can not only comply with applicable laws but exceed in evolving flexibly to shape sustainability goals, regulatory requirements, and align themselves with the evolving market expectations for greater operational flexibility.

The growing institutional momentum within the European Union to develop and support in-space refuelling technologies, and the European Commission's recognition of the role in-space operations and services (ISOS) play in enhancing the performance of space assets speaks to the strategic importance of in-orbit refuelling and services for long-term space sustainability, resilience and autonomy. The ESA initiatives on a potential Geostationary Service Vehicle (GSV) for in-orbit inspections and intervention of geostationary satellites, and a multi-capability space servicing vehicle with refuelling, refurbishing and boosting abilities for satellites in orbit, foretell a well-established pattern in the space sector, where foundational technologies are first adopted through Government led programmes before catalysing commercial markets. This predictable trend is already being embraced by the commercial sector's investment in the European Commission's objectives to map liability, licensing and insurance aspects of ISOS to stimulate market growth, and standardisation as well towards ensuring interoperability of developed products and services.

The Loop network envisages this rapid evolvement from Government-enabled strategic capability to commercial norm, to becoming an operational expectation across the satellite industry. The Loop network delivers a robust, cost-efficient, and sustainable refuelling service that extends satellite lifespans and empowers operators to plan for more resilient, high-performance missions. In an environment of heightened regulatory scrutiny and the push for more efficient and sustainable space operations, Loop provides a forward-thinking solution that ensures operators remain agile and competitive as the space landscape continues to evolve, and are prepared to benefit from the imminent ISOS growth.

By integrating in-orbit refuelling into mission planning, operators can achieve superior compliance, optimise their return on investment, and seize new opportunities for sustained growth and success in the space sector. Dawn Aerospace's Loop network is not simply a technological breakthrough, it is an essential enabler for building better regulatory alignment, and is a critical enabler for the future of space sustainability, operational efficiency, and long-term mission excellence.

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