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Advancing Space Technology for ISAM Maturity and Success

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Similar to the golden age of flight 100 years ago, today we are in the golden age of commercial space. New space missions – In-Space Service, Assembly, and Manufacturing (ISAM) in this case - are enabling capabilities in space to expand the space economy, improve life on earth, and extend our use of space farther than ever before.

Keyword: ISAM (In-Space Servicing, Assembly, & Manufacturing)

1 ADVANCING SPACE TECHNOLOGY FOR ISAM MATURITY AND SUCCESS

The new space economy is open for business. With an estimated value of $1.8 Trillion by 2035[1], the rising commercialization of space operations and exploration is attracting startups, investors, and the major space OEMs alike. Private sectors are leveraging their resources and capabilities to advance the space ecosystem, while governments are embracing the involvement of private companies.

Over the past years, this collaboration has increased the interest and investment in new space opportunities. In 2022, startup space ventures attracted eight billion U.S. dollars in financing.[2] There are predicted to be 4,000 to 5,000 satellite launches per year by 2030.[3] Additionally, the number of active satellites in-orbit is expected to grow three times within the next decade.[4] With investment, access to space, and satellites on-orbit all increasing, new space players can progress ISAM technology to achieve a resilient space economy.[5]

There are over 35,910 objects regularly tracked in space and we have seen over 640 break-ups, collisions, or other events resulting in fragmentation.[6] As the number of objects continue to increase, so does the probability of collisions and unexpected events. The Kessler Syndrome [7] denotes a scenario where collisions between orbiting objects – active or inactive – create more space debris, resulting in a domino effect of future collisions and eventually creating unusable areas in orbit.

Curbing the space junk cascade and achieving the new space economy's full potential will require a more sustainable approach to space operations. If industry and government players continue with a throwaway mindset when designing and building satellites, how can the new space economy keep expanding? New generations of spacecraft designed specifically for in-space

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[1] *https://www3.weforum.org/docs/WEF_Space_2024.pdf*

[2] *https://brycetech.com/reports/report-documents/Bryce_Start_Up_Space_2023.pdf*

[3] *https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/space-launch-are-we-heading-for-oversupply-or-a-shortfall*

[4] *https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/the-role-of-space-in-driving-sustainability-security-and-development-on-earth*

[5] *Defy Limits With Space Technology | Aerospace & Defense - Dassault Systèmes® (3ds.com)*

[6] *ESA - Space debris by the numbers*

[7] *Understanding the misunderstood Kessler Syndrome - Aerospace America (aiaa.org)*

servicing, assembly, and manufacturing (ISAM) offer a solution. ISAM capabilities overcome conventional paradigms of launching 'one and done' assets by improving spacecraft performance, availability, and lifespan.

ISAM started in 1961 in the Gemini program with demonstrations of rendezvous, proximity, and docking operations. NASA continued to advance this mission area with programs like Skylab, spacecraft repair missions with the Space Shuttle Fleet, assembly of the International Space Station (ISS), and robotic refueling missions – among others. [8] Fully advancing commercial ISAM capabilities and incorporating them into tomorrow's space systems will improve resiliency and flexibility, expand space mobility and logistics, and form the foundation for more sustainable and innovative space operations and exploration. Commercial ISAM is on upward trajectory towards establishing an active ecosystem. All-new space players are leveraging digitalization and simulation to defy the barriers to enter the ISAM market, accelerate its technological maturity and succeed in the new space race.

2 THE POTENTIAL OF IN-SPACE SERVICING

Since 2008, 80 satellites in geosynchronous orbit (GEO) have suffered anomalies that could have benefited from on-orbit servicing.[9] In-space servicing of satellites can significantly extend the life of the system and is a valuable tool for companies to extend service experiences that customers depend on.[10] This servicing portion of ISAM is a steadily growing market area. The on-orbit satellite servicing market is expected to reach nine billion U.S. dollars, globally, by 2031 at a 10.59% CAGR.[11]

According to the Center for Space Policy and Strategy,[12] ISAM refers to a broad suite of in-space capabilities that include:

- Space situational awareness and space object inspection and relocation
- Servicing: Altering or resupplying spacecraft
- Assembly: Aggregating or connecting pre-manufactured components
- Manufacturing: Transforming raw materials into components, products or infrastructure for use across industries terrestrially and in-space

[8] *Timeline of In-Orbit Servicing, Assembly, and Manufacturing (ISAM) Advances – Past, Present and Future | New Space Economy*

[9] *04_kunstadter_space_insurance_update_axa_xl_scaf_220111.pdf (nasa.gov)*

[10] *MEV-2 servicer successfully docks to live Intelsat satellite - SpaceNews*

[11] *On-Orbit Satellite Servicing Market to Reach $9.0 Billion, Globally, by 2032 at 10.59% CAGR: Allied Market Research (prnewswire.com)*

[12] *Game Changer: In-Space Servicing, Assembly, and Manufacturing for the New Space Economy | Aerospace Center for Space Policy and Strategy*

ISAM capabilities are a technology enabler for building a responsible, safe, and commercially viable space industry. To prepare for an ISAM-driven space ecosystem, it is crucial to understand ISAM's drivers, full capabilities, and current technological maturity.

1. What is Driving Advancement in ISAM?

    a. An increasingly unsustainable space environment

Approximately one million debris objects from 1cm to 10cm are in space. Recalling the Kessler Syndrome, debris mitigation measures must be conducted now to prevent uncontrolled debris growth. Collision risks in low earth orbit (LEO) already threaten at least U.S. $35 billion of space assets, further emphasizing the clear and present need for debris removal actions and ISAM-incorporated spacecraft to stabilize the space environment. Shifting to sustainable systems – through life extension and/or upgrade also contributes to sustainability of the space environment.

    b. Renewed international interest

In the last decade, worldwide interest has spurred ISAM development towards ensuring we have a sustainable space environment. The White House published a national implementation plan [13] outlining a roadmap toward realizing ISAM-enabled opportunities. Following suit, the US Space Force's small business-focused innovation unit awarded contracts to businesses collaborating with research institutions to develop active debris remediation technology.[14] Similarly, The European Space Agency is conducting extensive work on in-orbit servicing and debris removal as part of its clean space initiatives.[15]

2. Unbridled technology growth

Innovations such as reusable launch vehicles are creating more cost-effective space systems. Progress in robotics and automation in space has also led to more feasible and practical ISAM concepts. Traditionally, a human-in-the-loop presence is necessary for space operations. The end goal, however, is autonomous operations, where artificial intelligence (AI)-powered systems can leverage predictive analytics to generate in-space solutions for servicing, maintenance and manufacturing. More sophisticated satellites and constellations will facilitate enhanced missions, capabilities and benefits to life on Earth.

3. What are some of ISAM's Capability Areas?

While ISAM capabilities began development in federal space programs over 60 years ago, development of commercial capabilities is rapidly growing with investment from both the public

[13] *NATIONAL-ISAM-IMPLEMENTATION-PLAN.pdf (whitehouse.gov)*
[14] *Orbital Prime - SpaceWERX*
[15] *ESA - Clean Space*

and private sectors. In the private sector, space logistics (On-orbit servicing, Space Situational Awareness, and Debris Mitigation) have been the leading types of funding round activities since 2019 with on-orbit servicing leading within the space logistics area.[16] In-space services meet satellite needs in orbit by providing transport, communication, life extension, situational awareness or debris removal.

Examples of Space Servicing Areas (not an extensive list)		
Servicing Areas	**Description**	**Orbit**
Orbital Tugs	Transport satellites to the correct orbit after launch and remove them at end of life	GEO
Orbital Servicing, Life Extension and Refueling	Prolong satellite life by providing power or fuel in orbit	GEO
Debris Removal	Protect existing satellites by removing debris or dead satellites	Primarily LEO
Space Situational Awareness	Improve orbital environment understanding, predict conjunctions in orbit, and track debris and satellites	Primarily LEO and GEO

Table 2-1: Examples of space servicing areas.

In-space assembly enables the connection of components to create larger, more complex structures. In-space manufacturing (for structures, parts, and goods) transforms raw or recycled materials to fabricate structures in space.[17] Both capabilities are active from LEO to GEO and beyond.

[16] *https://www.spacecapital.com/space-iq*

[17] *https://www.nasa.gov/nexis/isam/*

Examples of In-Space Assembly & Manufacturing (not an exhaustive list)	
Assembly Areas	**Description**
Structured Assembly	Build structures using pre-manufactured components by assembling them in space.
Surface Construction	Connect infrastructure on a planetary surface using Earth- or space-based materials.
Manufacturing Areas	**Description**
Parts and Goods Manufacturing	Produce components in space from Earth- or space-based stock materials.
Recycling, Reuse and Repurposing	Transform spacecraft, parts and materials for new usages and purposes.
Surface Construction	Construct, excavate and outfit infrastructure on a planetary surface with Earth- or space-based materials.

Table 2-2: Examples of in-space assembly and manufacturing.

The full breadth of ISAM capabilities will foster an active space ecosystem characterized by ongoing space debris removal, in-space services such as refueling and repositioning, and satellite repair and upgrade. Through ISAM, the new space environment will be one where human-made objects are in space for a purpose, not due to abandonment or end of life. Implementation of ISAM changes our approach from throwaway to sustainable.

1. How Mature Is ISAM Today?

ISAM technology development began with the Gemini program and progressed to refueling capability demonstrations by Progress and Salyut a decade later. The Space Shuttle demonstrated multiple astronaut-assisted retrieval and repairs of satellites. In 1986 a Soyuz T-15 retrieved and transferred cargo from Salyut 7 to Mir. Each of these incremental steps was enabled by maturing technology and creative approaches to fulfilling needs.[18] Today, commercial capabilities have emerged.

Some examples include:

[18] *The Development of In-Space Servicing, Assembly, and Manufacturing Technology: Drivers, Challenges, and Policy Implications | RAND*

- Changing orbits and extending the life of systems as demonstrated by Northrop Grumman Space Logistics Mission Extension Vehicle (MEV).[19]
- Astroscale completing a technology demonstration of their inspection, rendezvous and proximity operations capabilities in LEO in 2021 and successfully demonstrating fly-around observations of space debris in July of 2024.[20]
- NASA has contracted commercial companies for space station fielding by 2030 to replace the ISS.[21] Axiom Space, Blue Origin, and Nanoracks are leading the assembly of these commercial destinations in-space to be a foundation for space-based laboratories and shop floors that will create capabilities for manufacturing in-space.

Based on ISAM use cases, in-space servicing and assembly capabilities should be ready for deployment in the next five years. Although in-space manufacturing could take longer, private companies can acquire a more prominent role in the new space market by creating added value in novel areas.

3 ISAM Adoption: Barriers and Recommendations

Getting new space systems active and operational is challenging, and three critical barriers affect ISAM adoption in the new space economy:

- Lack of successful demonstrations of ISAM abilities by industry
- Lack of standardization from agencies or adoption of standards by industry
- Lack of collaboration to shift from past models of design and operation of space systems

These barriers must be addressed for ISAM to enable the next generation of civil, national security, and commercial space missions.

1. Demonstrations

Satellite companies do not yet have the operational history of ISAM successes they need to adopt ISAM capabilities and standards with confidence. Real-world demonstrations in space take time and resources. A history of successful and affordable ISAM technology demonstration from commercial providers is still emerging. Additionally, short-lived satellites and reduced launch costs are making replacement satellites cheaper than servicing or life extension activities, especially for small satellites (SmallSats). In the long term, however, this scenario is not sustainable – launching new satellites into space while disregarding malfunctioning or dead satellites further contributes to the space junk cascade.

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[19] *https://www.northropgrumman.com/space/space-logistics-services*

[20] *https://astroscale.com/astroscales-adras-j-continues-to-make-history-successfully-demonstrates-fly-around-observations-of-space-debris/*

[21] *Commercial Destinations in Low Earth Orbit - NASA*

Accurate and convincing ISAM performance demonstrations will show that servicing and life extension activities are more valuable than replacement spacecraft. Digital engineering, vs traditional file-based approaches, leveraging model-based systems engineering (MBSE) and simulation enables startups and OEMs to establish a strategy to validate and verify requirements before comparison against functional, logical or physical representation. This helps them conduct comprehensive analyses of system engineering choices and associated trade studies to fine-tune the accuracy of their proposals.

Simulation capabilities have greatly advanced to aide in the development of new space systems. High fidelity, physics-based simulation enables new space players to cut overall ISAM demonstration timelines. For example, collaborative structural simulations enable all teams to work together to quantify and upgrade the structural performance of subsystems and components during the launch process.

This results in significant reductions in development time, reductions in the cost of physical testing, and less time spent on efficiency improvements. A digital environment enables stakeholders to collaborate on the same platform where they can swiftly define system architecture, verify prototypes, optimize manufacturing processes and get ISAM capabilities proven and market-ready ahead of the competition. Dedicated demonstrations will show the effectiveness and availability of ISAM technology so new space players can accelerate its adoption.

2. Standardization

While there is a standards compendium available from the U.S. Office of Space Commerce[22], it is broad and specifics for ISAM are yet to solidify. Today's new space industry lacks consensus on the interoperability of space systems. Insufficient standards in interfaces, modularity, certification and operational safety make it difficult for ISAM capabilities to benefit all. Standardizing regulations and engineering interfaces promise to promote ISAM adoption by lowering entry barriers, nurturing competition and decreasing satellite maintenance costs.

Some companies have openly shared their designs and standards for docking and refueling ports. These initiatives are changing the current space paradigm and promoting a forward-thinking, integrated space environment.

3. Collaboration

As the space industry expands, there is a growing need for improved collaboration between governments and private organizations to divert us from an unsustainable space environment. All new space players must work together to create an active ISAM ecosystem. The question is: How?

[22] *Space Industry Technical Standards – Office of Space Commerce*

Space industry architecture, along with its participants, roles and rules, has not evolved as quickly as space technology.[23] With siloed ways of working, it will be more challenging for the industry to generate a consolidated strategy to advance ISAM adoption.

Evolution from file-based systems into collaboration in a secure environment where private companies, research institutes and government bodies can work together on the most updated information is a critical enabler. With complete industry visibility, new space players are empowered to build an active and sustainable ISAM ecosystem together. Companies also gain traceability within and across their teams, ensuring efficient and agile approaches across the product or service lifecycle.

4 Conclusion

As new space players prepare to conquer the new frontier of space, the next generation of space systems is emerging, paving the way for more sustainable space operations and exploration. ISAM capabilities hold the answer to new space progress. Technologies such as digital twins and virtual twins turn physical objects and the processes associated with them into interactive and collaborative models. Leveraging the advantages of digital engineering is vital to advancing ISAM maturity and success.

Additionally, simulation with digital engineering elements can reveal insights and allow refinement of products and processes before fielding into space where realization of errors or better ways are too late or too costly to change. A century ago, aviation was entering the golden age of flight. Similarly today, the golden age of commercial space is upon us and ISAM capabilities are pivotal in driving new space progress.

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