30 June 2022

To: Dr Ezinne Uzo-Okoro
Assistant Director for Space Policy
Office of Science and Technology Policy

Subject: Response to OSTP's Request for Comments on the In-space Servicing, Assembly, and Manufacturing (ISAM) National Strategy (87 FR 26377)

Dr Uzo-Okoro,

I'd like to provide some input in response to your request for comments on the ISAM National Strategy you and your team released this spring. By way of background, I'm a serial space entrepreneur with over a decade experience in the ISAM industry. I'm currently operating as a freelance aerospace consultant, but prior to that was the Vice President for On-Orbit Servicing at Voyager Space Holdings, was a member of the Executive Committee of the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS) and was the founder and CEO of ISAM technology development startup Altius Space Machines, running that startup for over a decade prior to its acquisition by Voyager. These comments are based on lessons I've learned the hard way from trying to run an ISAM-focused startup, but I'm hoping that I can be seen as a little more objective now that I'm no longer a shareholder in any specific ISAM venture.

Before jumping into specific thoughts in response to the five question areas in the RFC, I'd like to reiterate how happy I was to see the National Strategy document your team released this spring. While how successful a strategy ultimately is will depend in large part on the implementation details, I think you provided a solid foundation for guiding future US government ISAM policy with your strategy document.

In the following subsections, I'd like to address each of your five question areas in sequence.

Question 1: What specific technologies and capabilities require priority R&D focus to enable and advance the development of a suite of commercial ISAM capabilities over the next 10-15 years?

While I imagine many of my colleagues throughout the ISAM industry have pointed out a many valuable R&D priorities, I wanted to highlight the ones that were from my perspective most worth considering:

1. **Backup Controlled Disposal Technologies:** As commercial and government activity in LEO rapidly proliferates, the ability to guarantee that every space object launched can be disposed of in a safe and controlled manner becomes increasingly important. While in the past, it has been acceptable to just minimize the amount of time post-mission that an object remains a hazard on-orbit, I believe the gold standard in the future will be making sure that all space objects are controlled and capable of performing collision avoidance maneuvers until they have lowered themselves to an altitude where they aren't a hazard to other operators (especially operators of

human spaceflight facilities like ISS, Tiangong, and future CLD developers). In order to maximize the probability of achieving this goal, it would be helpful to develop a range of technologies for providing backup controlled post-mission disposal, in the event that the primary spacecraft loses maneuverability or is in some other way disabled. These could range from grapple fixtures, backup deorbit propulsion systems, or semi-passive electrodynamic and/or aerodynamic drag devices who can have their drag properties modulated externally. The goal would be to determine the best mix of technical reliability and cost to the client spacecraft operator.

2. **Tumbling Space Object Capture Technologies:** Currently many space debris objects are tumbling. Funding to develop and demonstrate a range of approaches for capturing and detumbling (or vice versa) space objects would be valuable, including both unprepared legacy space objects, as well as objects outfitted with grappling fixtures. Some of these technologies are already being developed in private industry by companies like Altius, Astroscale, Kall Morris, Clear Space and others, but I think most observers still consider this to be a high-risk area that could benefit from both R&D and flight demonstration.
3. **Modular Power/Data Interfaces and Adapters:** For both in-space servicing and assembly, one of the key capabilities is the ability to add or remove modular payloads or instruments. This requires interfaces capable of making a physical connection that can also transmit power and data between the client spacecraft and the attached module. There are already many US and international companies working on different modular power/data interfaces including Altius, NovaWurks, iBoss, SpaceWorks, Tethers Unlimited, CU Aerospace, and many others. However, there are still several areas that could benefit from further R&D funding:
    a. **Launch Hardened Interfaces:** Interfaces that can double as ground-attached hosted payload interfaces can help make modular interfaces more economically interesting to commercial spacecraft that may be skeptical of the value proposition of modular interfaces for repair/upgrade of their spacecraft.
    b. **Interface Adapters:** I'll touch on this later in this response, but one of the biggest fears I've seen on the government side regarding modular power/data interfaces is the fear that they'll put the wrong interface on their spacecraft. One way to ameliorate that risk is to deliberately fund promising interface developers to develop adapters between their interfaces and those of another promising interface adapter.
    c. **Client/Interface Software:** For many of the interfaces in development, most of the focus has been on the physical latching and power/data interface, while much less work has been done on trying to develop software for enabling client spacecraft to talk to modules through the interfaces. The more this can be standardized, the easier it may be to make physical adapters between different interface standards.
4. **Technologies/Capabilities for Retrofitting Legacy Spacecraft for Modular Serviceability:** Because most satellites have not yet been designed for modular serviceability, the addressable market for modular servicing is relatively small. But just as life extension operator Northrup Grumman has shown with MEV, it's possible to dock to legacy, unprepared client spacecraft to perform beneficial servicing missions. An exciting new area that could use further R&D funding is developing hardware that can be attached to legacy satellites making them capable of some level of modular servicing in the future. One example of that is the ModPak technology that my former colleagues at Nanoracks are developing under the Orbital Prime program. Having the ability to retrofit legacy satellites for servicing can both accelerate the development of servicers

and modules, but also serve as "training wheels" to get satellite operators used to the operational flexibility that modular servicing can provide them. It will likely be a lot easier to convince satellite developers in the future to bake-in modular features if their customers have gotten used to the benefits and understand the limitations they face if they don't build those features in from day one.

5. **LEO Propellant Depots and associated technologies:** This one is somewhat of a hobby-horse of mine, but I think there's a lot of potential for LEO depots focused on refueling small launch vehicle upper stages, to enable sending small/medium class missions beyond LEO faster and more affordably than can be realistically done with other options. These depots can serve as learning-grounds for enabling larger multi-user depots for large human spaceflight missions in the future. Technologies that LEO depots could use include rendezvous and prox-ops (RPO) that is optimized for maneuvering rockets to depots with the minimal added complexity, and cryogenic and bulk storable propellant transfer that minimizes the added mass to the launch vehicle and is flexible for a wide range of vehicles that may have fueling ports in different areas. But ultimately this is more than just about developing the technology, but about establishing the capability, and using it enough for it to be part of our country's toolchest for future commercial and government operations.
6. **Technologies for manufacturing large pressure structures on-orbit:** While there are probably many in-space manufacturing technologies worth funding, one that I don't see a lot of funding for yet is the ability to manufacture large, leak-tight, pressure structures on-orbit. Most in-space manufacturing I've seen to-date has been focused on apertures and truss structures. Both of which are definitely important, but even with the advent of much larger launch vehicles like Starship, there's always the challenge of wanting volumes too big to launch in one go. Inflatables can help to a point, but having the technologies for fabricating arbitrarily large propellant tanks, or large pressurized habitable volumes on orbit could be very useful in the long-term, and the next 5-10yrs is probably the time to try out several approaches so they're debugged and on the shelf for the ambitious projects of the 2030s – whether that's human spaceflight propellant depots, larger human spaceflight facilities following-on the CLD systems under development today, or even something fun like a zero-g orbital Quidditch Pitch.

Question 2: What infrastructure, ground, space-based, or digital, or other non-monetary resources will be critical to enabling the advancement of ISAM capabilities and the commercial ISAM industry?

The one piece of ISAM-enabling infrastructure that doesn't exist yet but that I think would be most beneficial is an orbital facility optimized for testing out ISAM-related technologies. I know that Dr Roberta Ewart's group at USSF Space Systems Command has been pioneering a concept called the Advanced Space Testbed (XST) for providing this capability to the DoD. ISS already provides some of these capabilities, but also comes with a lot of challenges and limitations due to its nature as a $100B irreplaceable national asset. To me, an ideal ISAM orbital test facility would have the following features:

- **Capable of High Risk-Tolerance:** There are a lot of ISAM technologies and capabilities that are hard to test on a platform like the ISS because of its risk posture. An ISAM test facility needs to be a place people can try things earlier in the process, where there's often more information to be gained, and where lessons learned can save a lot of analysis paralysis.

- **Human-tendable:** I think there's some real benefits from having a small, inexpensive habitat/workshop where humans can visit when it's value added. One of the benefits of a test facility like Edwards AFB for the DoD is the ability to do rapid modifications and retest something soon thereafter. While I don't think you want something continuously crewed, having that option provides flexibility.
- **Co-orbital with another Human Spaceflight Facility:** If you can tap into the crew/cargo logistics stream of a larger facility without dealing with all of the red tape associated with it, it can make it a lot cheaper to operate a testing facility.

Question 3: What factors (*e.g.,* demand for services, lack of regulation, government funding, USG space priorities and space architecture decisions, significant debris event) may accelerate or decelerate progress in the development and advancement of the ISAM industry?

The ISAM industry is still extremely nascent, and while risk capital has been more available for the past year or two than it has at about any time in my career, it's unclear how much of that will change if the overall financial markets continue to cool off over the coming months. One of the big questions for investors is whether the market is really ready for investment, and many investors I've spoken with still think the main ISAM market is 7-10yrs out. I think though that there are a few areas where wise focus by the federal government can enable the ISAM marketplace to mature a lot faster than would happen otherwise.

Breaking the modular serviceability chicken and egg problem

The first challenge I've seen is that there is a "chicken and egg" problem when it comes to modular servicing and assembly. Client satellite operators right now are reticent to design their satellites with serviceability features (like grapple fixtures, refueling ports, and modular power/data ports) because it's unclear when servicers will exist to affordably interact with those features. That reticence makes it hard for servicing developers to raise money to develop servicers because investors see a small addressable market and a long delay between initial servicing operations and when real customer demand can ramp up. There are now a few servicing companies trying to address this market anyway, and some of the interface companies are trying to find other ways to break the chicken and egg problem (by making interfaces that provide some value to the clients whether or not servicers exist), but the government could help accelerate this process and avoid the risk of it taking several years longer than it needs to.

Most importantly, as one of the main operators of large spacecrafts in LEO, MEO, and GEO, the federal government could set an example by baselining design for serviceability as a requirement for future government missions. While they can grant exceptions for cases where servicing truly doesn't make sense – like say a space probe that's going to be leaving the solar system after its mission and thus has almost no chance of ever being interacted with again – having design for serviceability as the standard practice could help a lot in helping both servicing companies demonstrate a larger addressable market, and also help encourage commercial companies to start designing for serviceability, knowing that they won't have to pioneer the use of modular servicing all by themselves.

As mentioned earlier, one of the big reasons I've heard why government clients haven't started including servicing interfaces, especially modular power/data interfaces, is the concern that they'll pick the wrong interface. The historical analogy people tend to think of is VHS vs Betamax. They don't want to build using the wrong interface ecosystem and end up not actually being able to use the interface when they need it. I've seen the government trying to push organizations like CONFERS to endorse a specific interface that they can standardize on or threaten to pick one themselves. But I think that delaying adaption of modular power/data interfaces until the One Interface to Rule Them All™ is developed or trying to prematurely force a downselect to one specific interface before we have significant operational and market experience with those interfaces are both unwise, and unnecessary. I think the fear of picking the wrong interface is somewhat misplaced, but also something the government can take actions to mitigate.

First, I think the concern of picking the "wrong" interface is somewhat misplaced. Modular power/data interfaces are more like the various interfaces on a computer or laptop than VHS vs BetaMax tapes. So long as the interface has some level of competently implemented power transfer, and some form of competently implemented data transfer, it's almost guaranteed that you can find a way to make an adapter between it and some other flavor of power/data interface. Much as regardless of what ports your laptop has you can almost always find an adapter that lets you plug in your new second monitor or printer. There may be some performance lost, and there's a mass and cost penalty, but *having any competently implemented power/data interface is almost infinitely better than having no interface,* even if it turns out you picked a less-popular design and end up having to use an adapter.

But as hinted at earlier, one thing the government can do to further mitigate the downside of choosing the "wrong" interface, is by using its leverage as an early customer to insist on interface developers agreeing to interoperability. When Altius sold its DogTags™ grapple interfaces to OneWeb, part of the deal was that OneWeb owned those interfaces once they were delivered and could choose to use whichever servicer they wanted to interface with it. Altius could try to develop a servicer, but OneWeb wasn't locked into Altius's servicing ecosystem, unless we provided the best value. Altius agreed to provide ICD data and even sell copies of the interfaces to any developer who wanted to develop a grappling system compatible with DogTags. The government could take a similar approach to modular power/data interface developers. Basically, as a requirement to be a government customer get them to agree to publish enough information on the module-side of their interface to enable anyone to develop a compatible module or an adapter between their interface and another interface design. Maybe even fund development of adapters between popular interface ecosystems.

That way, people can start using interfaces and getting real operational experience with what works best and what doesn't, without worrying about getting stranded with an unpopular interface. Over time, customers will likely naturally downselect to a few interfaces, but based on actual experience rather than trying to guess things a priori.

Lack of awareness about the Art of the Possible for ISAM

Another big challenge facing ISAM developers, is that because ISAM hasn't been widely used yet, people don't have a great understanding of how it can be used, and what economics are affordable. Most of the examples they've seen of on-orbit servicing/modularity are things like Hubble servicing, DARPA's Orbital Express, and the RESTORE-L/OSAM-1 mission, which leads them to believe that servicing has to cost hundreds of millions of dollars for one-off missions, and thus isn't very relevant to them. Companies and organizations like CONFERS are trying to do the missionary work to educate customers about what is actually possible with ISAM, but this is an area where government-funded studies might help accelerate things faster. Both by being seen as an unbiased source compared to a specific company or industry association, but also by the very act of talking with potential government end users and helping them see how servicing could help their missions.

Creating a procurement path to repeatable business

In order to convince investors to put significant money into ISAM capabilities, they need to believe that not only are there customers who need ISAM capabilities, but that there are near/medium-term paths to them being able to pay for procuring those services on a frequent enough basis to justify the investment. As one of the largest operators of the kind of high-value spacecraft that could most benefit from ISAM, the federal government is potentially a very important customer for ISAM operators, but to-date there has been almost no federal government ISAM spending beyond the R&D and tech-demo stage, and no clear path to getting there.

One-off tech demos are useful on some level both to reduce technical risk, and provide some financial payback to a company, but there has to be a clear path to follow-on work or raising investor funding is much harder. Right now, if a government satellite operations group saw a clear technical benefit from servicing their satellites, it's unclear that there is a near-term way for them to purchase those services through the system. There may be clever workarounds and one-offs, but until there is a clear pathway for interested government customers to actually buy ISAM services on a regular basis, it's going to be hard to attract investment. But if ISAM services become a standard part of the budget for a satellite program, just like launch and spacecraft procurement, and there's clear budgets for procuring such services, it will likely become much easier to secure investor support for ISAM ventures.

Quantifying and determining the optimal risk mitigations for LEO megaconstellations

The development of LEO megaconstellations is one of the major trends in the current space economy. My worry is that there are several externalities and grey swan risks posed by LEO megaconstellations that are currently unquantified, and thus not being really addressed:

1. **Risk to Human Space Facility Operations:** Most LEO megaconstellations (other than OneWeb and TeleSat) are not baselining the use of grapple fixtures or other means to ensure backup controlled disposal if the satellite fails or loses maneuverability. They justify this because they're flying at a low enough altitude (typically 500-600km) that the satellite is guaranteed to passively decay within <25yrs. But most of these constellations intend to operate at altitudes above those of human space facilities like the ISS, Tiangong, and all of the Commercial LEO Destinations that NASA is currently funding. This means that failed megaconstellation satellites will eventually drift down through the operating altitudes of these facilities and will impose added collision avoidance maneuvers on human spaceflight operators. Collision avoidance maneuvers have sometimes required ISS astronauts to pause operations and hunker down in escape vessels. Nobody so far has quantified the seriousness of this nuisance, how much cost that will impose on those operators, and if it's appropriate to allow LEO megaconstellations to pass off those costs on HSF facility operators vs requiring them to take additional mitigation steps. Maybe the cost is miniscule, but without knowing it's hard to tell if current practices are acceptable or not.
2. **Carrington Event "Grey Swan" Risks:** We live around an active star that sometimes misbehaves. The combination of massive LEO megaconstellations and space weather provides the potential for a grey swan event if a Carrington Event class solar storm were to disable a large percentage of megaconstellation satellites at the same time. Nobody has yet simulated a scenario this

severe, what its repercussions would be, what the probability are of it happening, and nobody has analyzed the best methods to mitigate this risk, and how best to share the cost of such mitigation between commercial operators and the government.

If we understand the risks, we can figure out how best to craft government policies to mitigate them (if they need to be mitigated) without imposing undue costs on any particular actor. Right now, most of the megaconstellations do not see themselves as ISAM customers. But if it turns out that, as many currently suspect, they're creating externalities for other operators, a better understanding of that scope of that externality could help more equitably share costs and could accelerate the development of the ISAM industry, if using ISAM services (such as backup post mission disposal services) are found to be the best way to mitigate those costs.

Question 4: What are the most effective kinds of partnerships, between the U.S. Government, industry, and academia, that would advance ISAM industry maturity and ISAM capabilities? What partnership opportunities exist, both nationally and internationally, outside of the Federal Government?

I don't have a lot to offer on this question other than that public/private partnerships, when done well can help unlock capabilities much more affordably, and often more innovatively than can be done through purely government channels. But to truly unlock private investment to augment government investment, you need to make sure you're helping create a market that justifies the private investment. Some of the public/private partnership initiatives that NASA has attempted have struggled because of a lack of clear commercial (or at least ongoing NASA) demand.

Question 5: What are the highest priority actions that the USG can take over the next five years to implement the goals outlined in the ISAM strategy?

Building on my earlier comments here are what I think are the top five things the USG could do over the next five years to advance the ISAM industry and implement the national strategy your team developed:

1. **Make the Commitment to Mitigate Long-Term Debris Concrete:** The commitment from the national strategy to mitigate long-lived debris is a great aspiration that could be made a lot more concrete and tangible. Set specific goals and deadlines for remediating existing US govt debris (e.g., removing all US government owned debris of >50kg mass before the end of 2035). Assign a responsible US government organization to oversee accomplishment of the goal, and work with Congress to request sufficient funding to achieve it.
2. **Quantify Megaconstellation Externalities:** Fund research to quantify the externalities caused by large LEO constellations and assess the best ways to deal with these externalities. If these risks are real, ISAM services are likely an important part of the solution set.
3. **Set an Example on Design for Serviceability:** Require all future US government satellites to design for serviceability and procure some form of backup post mission disposal services or insurance. Eventually, we need to move to a future where nobody leaves dead satellites on-orbit for even short periods of time. Getting to that future will be easier if the US government sets a good example for commercial operators. Also, for future purchase of commercial space services, prioritize purchasing services from commercial entities that are also designing for serviceability and procuring some level of backup most mission disposal services. If commercial operators see that government wants to incentivize a behavior, they're more likely to adapt it.

4. **Create a Clear Way for USG to Be an ISAM Customer:** Develop clear procurement mechanisms to enable future purchase of ISAM services, and working with Congress, factor ISAM services into future presidential budget requests. It might also be worth finding ways to try and incentivize current and future space mission developers/operators to take a risk on factoring ISAM services into their planning. If agencies performing space mission knew that if they saved a lot of money by procuring ISAM life-extension/enhancement services, that they'd get to keep some of the savings to reinvest in R&D and other priorities they care about, they'd likely be more excited to take a risk on something new.
5. **Help Paint the Art of the Possible for ISAM:** Fund technical/economic studies illustrating the art of the possible for ISAM to help educate current and future space mission operators.

Thank you for the opportunity to respond to the Request for Comments. I think the strategy you've created is a great foundation to build on, and hopefully these suggestions can help in implementation. If you have any follow-up questions or want clarification on any of the ideas I mentioned, don't hesitate to contact me.

Sincerely,

Jonathan Goff
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