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Response of The MITRE Corporation to the NSTC RFC on In-space Servicing, Assembling, and Manufacturing

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About MITRE

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MITRE's experiences with in-space servicing, assembling, and manufacturing (ISAM) center on space and airspace traffic, debris, worker health, and building consensus for collaborative decision making. We've focused on providing insights along these lines within this response.

Questions Posed in the RFI

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?

Minimize Impacts on Global Airspace. MITRE believes that the greatest research and development (R&D) need isn't derived from a technological capability gap, but rather from investigating ISAM systemically. As ISAM grows, the number of Earth-to-orbit (and return) trips will significantly increase to deliver materials to and from space. Our current approach of shutting down portions of the airspace during these space-based transits will not scale and will need to be re-envisioned. R&D should thus be prioritized to develop new models and approaches for managing increasing space transits while simultaneously decreasing the impact on commercial aviation (and sea shipping).

Planetary Protection. R&D regarding technologies and capabilities to ensure space and planetary protection needs to be prioritized to ensure that biological materials, such as microbes, are not contaminating Earth or any celestial bodies, including the Moon. It is indeed equally important to prevent contaminating Earth with mutated pathogens on space-manufactured products as it is to prevent contaminating other celestial bodies with pathogens from objects produced in Earth orbit.

Worker Health. ISAM will require human crews and workers. The health and human side-effects of working in space need research and development to establish what the risks are, and what the safety metrics need to be. It is highly unlikely that all existing Occupational Safety and Health Administration (OSHA) thresholds will be achievable in space, so research and data are needed to determine what the space-specific worker protection criteria should be. Protection against space hazards such as acceleration/deceleration, aerosols, barometric pressure, debris, microbes, microgravity, noise, radiation, spatial disorientation, extreme temperatures, and vibration is required for persons who may not meet the strict health requirements of astronauts.

The Commercial Spaceflight Federation (CSF) and MITRE collaborated to convene a workshop in May 2021 of experts from the space industry (Axiom Space, Blue Origin, Orbital Medicine, Sovaris Aerospace, SpaceX, The Boeing Company, Virgin Galactic), government (Department of Commerce, Department of Defense, Department of Health and Human Services, National Aeronautics and Space Administration, Federal Aviation Administration), and academia (Baylor College of Medicine, Boston Children's Hospital, Johns Hopkins University School of Medicine, Translational Research Institute for Space Health) to develop a research framework for examining spaceflight participants in preflight, in-flight, and postflight operations and activities. The objectives of the research plan are to better understand and mitigate possible adverse outcomes and make space more accessible to civilians, such as those who might work in space to build space infrastructure, mine precious and rare metals, and manufacture items that cannot be made on Earth. A research roadmap[1] for passenger health in commercial space was established following the workshop, in which important next steps were identified, such as research in space motion sickness, impact of space travel on preexisting health conditions, effects of acceleration forces and microgravity, cardiovascular responses to spaceflight, impact of radiation on the body, and psychological effects of isolation and distance from Earth.

ISAM Quality Assurance. Non-destructive testing methods, and particularly remote testing methods, need to be developed, and from those methods, made-in-space quality standards need to be developed. Customers of ISAM products will request assurances on the quality and performance of the products they are purchasing, particularly if those products are safety or health critical. Therefore, the technology to evaluate the characteristics and quality of these products needs to be prioritized to ensure that they are usable in the marketplace.

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?

An important, although nontraditional, infrastructure requirement is to ensure resilient collaboration and collaborative decision making between parties. This involves:

- Effective coordination within the government (between organizations), which is specifically mentioned in the Space Policy Directives
- Collaboration between industry, academia, and Government
- Coordination with the international community

[1] M. Marge. Summary Report: CSF/MITRE Workshop to Create a Human Research Program for Spaceflight Participants in the Commercialization of Space. 2021. MITRE, https://www.mitre.org/sites/default/files/publications/pr-21-2524-CSF-MITRE-Workshop-Human-Research-Program-Commercialization-of-Space.pdf.

Collaborative decision making for space has already been recognized as important by the Federal Aviation Administration, which is currently launching a "Collaborative Decision Making" group bringing together government and industry, with a focus on managing launches and reentries within the National Airspace System (NAS) ecosystem. MITRE has previously published a paper highlighting how collaborative decision-making principles can be applied to space vehicle operations into the NAS and has proposed a Space Collaborative Decision Making concept.[2]

The necessary collaboration and the current efforts to enable coordination are shown in **Error! Reference source not found.**. It is crucial for the U.S. government to start leveraging these existing structures to advance ISAM.

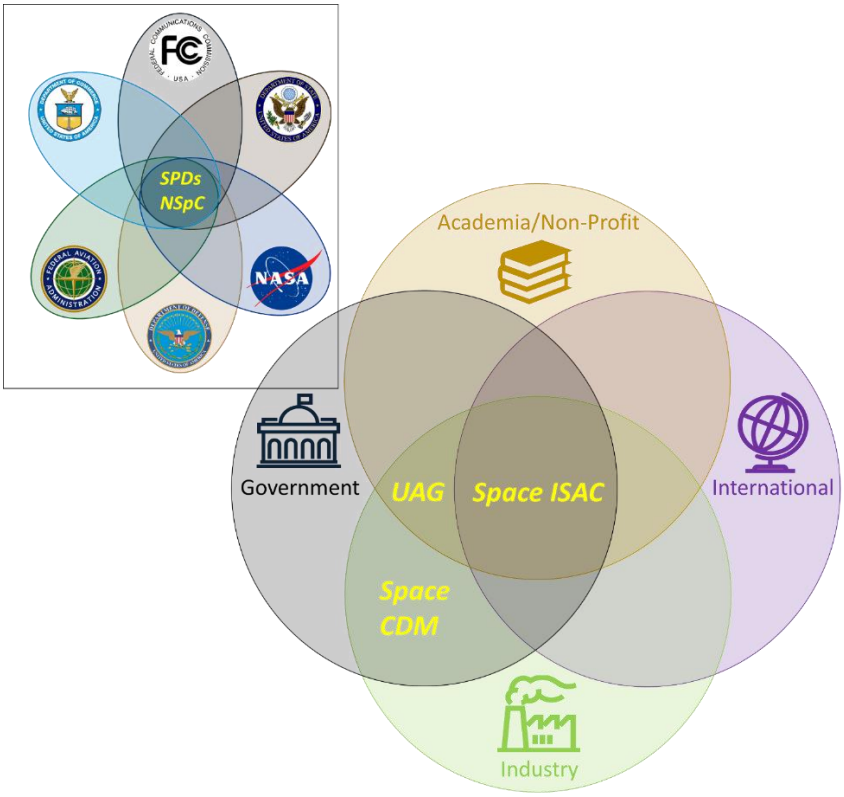

Figure 1. Collaboration needed between the actors of ISAM. SPDs: Space Policy Directives. NSC: National Space Council. CDM: Collaborative Decision Making.

Additionally, space is not currently considered as "critical infrastructure," although there have been several legislative proposals to make it so.

[2] C. Bolczak et al. Collaborative Decision Making for Space Launch and Reentry Operations: Concept Description. 2019. Space Traffic Management Conference, https://commons.erau.edu/cgi/viewcontent.cgi?article=1237&context=stm. Last accessed June 20, 2022.

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?

Airspace and Health Concerns. These were previously flagged in response to Q1 as research needs because they are limiting factors to ISAM advancement. Growth in ISAM will require many more launches and reentries into the NAS, with resulting concerns such as operational policies, environmental policies, system safety, economic impact vs. value analysis to inform said policies, airline negotiations, NAS infrastructure modifications (ground and digital), and training. If these are not proactively addressed, it will certainly decelerate progress.

ISAM will eventually evolve into having an in-space workforce that cannot be as closely selected and monitored as we have traditionally done for astronauts. Existing OSHA requirements may not all be appropriate or sufficient for space-based activities and will need to be reinvestigated.

Space-based Objects. Enhanced Space Situational Awareness and Space Traffic Management, including cislunar space, is essential to promote ISAM. The importance of debris tracking and removal will grow, and paradigms for dealing with manufacturing waste or byproducts must be developed.

Marketplace Considerations. While several manufacturing capabilities have already been successfully demonstrated in space, more have shown promise in laboratory environments, and commercial industry has historically excelled in developing technology to manufacture items in widely disparate and challenging environments. However, technology solutions still need to be developed and matured to better integrate marketplaces with goods that are produced in space, and to validate the quality and safety of in-space products and production systems. Prioritizing the development of these non-revenue generating technologies is essential to create a market ecosystem that makes "made in space" an attractive option for manufacturers and consumers, and is unlikely to occur without prioritized effort from the government. Moreover, the lack of regulations, standards, and guidelines is a significant hurdle to ISAM (and every other space initiative). The inadequate regulatory structure and undefined performance, quality, and safety standards limit the ability to safely incorporate in-space manufactured objects into the marketplace.

Nuclear Power. For the past several years, MITRE has been involved in safety guidelines for incorporating space nuclear systems into commercial spacecraft. One of the major challenges in this scenario is proving the safety and reliability of the system as it operates in Earth orbit without government oversight, and since these systems may also be used to supply heat or power for ISAM, the lack of on-orbit regulatory authority within the U.S. government is also a challenge for growing the ISAM industry.

Cislunar Consideration. To ensure the U.S. leadership in ISAM, the federal government should consider cislunar space and the lunar environment. This is no longer a two-body problem (Earth-Spacecraft) but a three-body problem that includes the Moon. Following the launch of the Artemis accords, NASA and its global partners are actively taking steps toward building a lunar base at the South Pole, which will inherently rely on lunar and Earth Orbit ISAM for habitat and mining infrastructure. Problems experienced in Earth Orbit due to the lack of adequate management (debris, traffic) will translate to cislunar if the USG does not take proactive actions

to regulate traffic toward the Moon. These steps need to be taken inclusively, i.e., with the international community, although the USG can lead the initial effort and therefore maintain its leadership role in the space domain. Research in this domain has begun, as demonstrated by published work on cislunar traffic management using resonance orbits.[3]

[3] C. Frueh, et al. Cislunar Space Traffic Management: Surveillance Through Earth-Moon Resonance Orbits. 2021. Proc. 8th European Conference on Space Debris, https://conference.sdo.esoc.esa.int/proceedings/sdc8/paper/261/SDC8-paper261.pdf.