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FACTORIES-IN-SPACE

1. Vision: Authors envision the establishment of "Factories-In-Space" for manufacturing, assembly, repair, and reclamation in non-terrestrial environments.

"Factory-in-Space": a centralized manufacturing hub for extracting/processing raw material, assembling products, and transporting finished goods to their final destination.

2. Background: The first steps on the moon by NASA astronauts left an indelible legacy that inspired many transformational technological achievements. Recent achievements by national and private entities (ISS, SpaceX, etc.) have spurred new commercial ventures, heralding the beginning of a "new space age." These pursuits are driven by interests like space tourism, asteroid mining, Earth defense, interplanetary travel, etc. National strategic interests, including air/space superiority and national security, are also aligned. Today, space-based objects, like satellites or spacecraft, are manufactured & assembled in factories on Earth and then launched into space on rockets, which is inefficient and expensive. A long-term vision of success for building "Factories-in-Space" mandates that we start asking fundamental questions today. *Can we describe the physics of how processes like casting or 3D printing would work in zero-gravity? What kind of materials can be used to construct production tools, like dies and inserts, to function in extreme environments? What kind of advancements in autonomous systems are needed to build machines, like robots and AGVs, that can maneuver to assemble components in space?*

3. Drivers: As there is a growing demand for launching satellites, supplies, spare parts, etc., this vision is critical as the cost and mechanics of launching any space-based object are exorbitant. Currently, the best cost-to-payload ratio for launching an object to low Earth orbit is nearly $1,000/lb. [1]. Moreover, because satellites and other objects have to be launched on rockets, they are designed to withstand incredible G-Forces, and are therefore over-engineered and inherently sub-optimal structures [2]. Additionally, obsolescence can be delayed as damaged systems can be repaired autonomously. Likewise, space-junk that is left behind from previous missions can be reclaimed. Unsurprisingly, this vision is challenging, given the nature of extreme environments that would be faced, including low/zero gravity, cryogenic/solar temperatures, hazards like radiation/electromagnetic storms, etc. This new paradigm will demand increased scientific and engineering innovation, as well as a multidisciplinary community working together to address the fundamentals. Importantly, this vision is also timely, as the tenuous link between the Earth and space relies on an increasingly integrated system of satellites. Currently, 1,459 satellites orbit the Earth [3]. The number of satellites is growing rapidly, e.g. "the number of small satellites launched during the first half of 2017 already surpassed the flight rate for all of 2016 [4]."

4. Programs of Emphasis: Examples of programs to execute the vision of "Factories-in-Space" include: (1) Autonomous space/surface based production technology; (2) Materials; (3) Factory design; (4) Logistics (transport/conveyance); (5) Power distribution/data systems; (6) Advanced satellite development (micro, degradable, etc.); (7) Space-based autonomous repair; (8) Reclamation of space-junk; (9) Safety/security systems; (10) Factory maintenance; and more.

References: [1] Sheetz, M. "Elon Musk says the new SpaceX Falcon Heavy rocket crushes its competition on cost." CNBC, Feb 2018. [2] Thompson, A. "How Building Satellites in Orbit Will Change Our Future in Space." Popular Mechanics, May 2017. [3] Klotz, I. "Small satellites driving space industry growth: report." Reuters, 2017; [4] 2017 SIA State Of Satellite Industry Report.