Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032

Topical White Papers

Summary

Metal additive manufacturing in the microgravity environment is a critical enabling platform technology for space industrialization and commercialization. Current approaches utilizing plastics and low-temperature metals cannot provide viable solutions for on-orbit servicing, assembling and manufacturing (OSAM) activities and prevent doing those activities economically. We strongly encourage the National Academies of Sciences, Engineering, and Medicine (NASEM) to recommend to NASA, Department of Defense, Department of Energy and other US government entities to put forward significant investment into development of high-temperature metal additive manufacturing technologies applied to space so as to open new space markets for commerce and next generation science.

Challenges of Metal Additive Manufacturing in Microgravity

Additive manufacturing in microgravity presents new and complex challenges as compared to terrestrial analogues. Current state-of-the-art microgravity additive manufacturing technologies have demonstrated manufacturing of plastics on the International Space Station and there are existing programs to demonstrate similar technologies for low-earth-orbit missions. In addition, there are programs under development for performing additive manufacturing of low-temperature metals in microgravity. However, plastics selected for NASA additive manufacturing systems, such as PEEK, do not provide the needed material strength to produce structural elements in microgravity and have shown significant degradation when exposed to radiation in space. In addition, these materials do not have the materials properties for supporting the structure and optics for next generation science observatories.

State-of-the-art microgravity additive technologies are modified terrestrial 3D printing systems. As such, these technologies are not optimized for space operations and have significant challenges when it comes to additive manufacturing of metals in microgravity, particularly at large scale. Specifically, input electrical power, directing the additive manufacturing material melt to the substrate in microgravity, and reducing additively manufactured surface roughness are the key technological challenges which require investments into new technologies.

1. There are significant electrical power limitations when performing activities on-orbit. Available power on the International Space Station for payloads ranges from 50 watts to 200 watts. Large spacecraft can accommodate slightly higher power loads, being able to provide peak power availability of 1.5kW to 2kW for small periods of time. However, industrial terrestrial additive manufacturing systems require 10's of kW as they use low energy efficiency power sources such as lasers or electron-beams to melt the material.

2. Terrestrial metal additive manufacturing systems utilize Earth's gravity to direct the molten metal onto the build plate. However, in microgravity there is no gravity vector to utilize. For existing microgravity additive manufacturing systems, this has been overcome by utilizing a push plate to exert a force onto the molten material. But for high-temperature materials, this approach is not viable because there are no known materials able to confine the melt material without degrading or failing.

3. Terrestrial and space-based additive manufactured surface roughness's range from 10s to 100s of microns RMS and require subtractive manufacturing technologies to smooth parts from rough finish into functional components. These subtractive manufacturing technologies burden mission operations by requiring additional mass, power and complexity. In addition, when smoothing the surface, material smoothed away must be captured, carrying an additional debris risk to the spacecraft subsystems as well adding potential projectiles in near proximity.

To overcome these challenges for additive manufacturing in space, new technologies optimized for microgravity and space flight operations are required. Microgravity metal additive manufacturing systems need to be re-thought, incorporating newer, more efficient power sources and new processes to perform manufacturing and article smoothing to enable large scale additive manufacturing of metals in microgravity.

Applications of Metal Additive Manufacturing in Microgravity

Microgravity metal additive manufacturing applications aggregated is a multi-billion dollar market including manufacturing of support structures, servicing of spacecraft, and performing joining services (similar to welding). More importantly, it can enable new in-space segments of the space economy and will lead to additively manufacturing spacecraft and pressure vessels.

Near-term specific applications of interest to both Department of Defense and NASA include:

- Solar array structures: Solar array support structures are the most massive subsystem on solar arrays with the array structures retaining up to 70% of total mass. This mass could be significantly reduced and thus allow for more energy generation in space by additively manufacturing the solar array support structures in-space.

- Telescope mirror structures: While it is currently beyond the state-of-the-art to additively manufacture mirror substrates, the majority of a telescopes mass is related to the structural mass of the telescopes mirror(s). And as seen on the James Webb, launch vehicles are forcing telescopes to become deployable in order to fit the telescopes structure, thus increasing both cost and risk of missions. Development of microgravity additive manufacturing technology in space could eliminate the need to utilize deployable mirror systems for next generation telescopes by building the mirror structure in-space supported by some on-orbit surface smoothing.

- RF antenna structures and substrates: Larger RF substrates and system structures will enable greater resolution synthetic aperture radar and higher performing communication satellites. This can be directly achieved through additively manufacturing the substrates and/or RF system structures in space to eliminate the launch constraints imposed by launch vehicles.

Additional areas of interests for the US government and industry include joining materials in space, modifying spacecraft through additive manufacturing, and repairing spacecraft through additive manufacturing. In the long run, space optimized additive manufacturing has the potential to produce spacecraft and pressure vessels directly on-orbit.

Recommendations

We recommend accelerated investments into new technologies to perform metal additive manufacturing in the microgravity environment of space. Investments should focus on developing innovative power sources, research into concepts to direct molten metal in microgravity, and advance dual purpose additive manufacturing concepts to perform smoothing of surfaces. Such investments must include performing technology demonstration space missions to verify and advance the targeted technology.