# Fundamentals of Manufacturing in Microgravity Space Environments

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## Abstract

**Statement of the Problem:** The fundamentals of manufacturing in microgravity space environments are becoming a strategic business choice that aims to produce materials and products that cannot be manufactured effectively on Earth [1]. Space missions performed during the latter half of the 20th century established the scientific basis for manufacturing in space commencing with the Mercury and Gemini programs progressing to welding and casting in space during the Apollo, Soyuz, Spacecraft and Skylab era (1950 – 1980) (Figure 1). Space Shuttle and Mir expeditions progressed the initial work with the Spacelab and the International Space Station (ISS) with the focus on manufacturing without containers, welding, deposition and crystal formation (solidification), characteristics required to develop additive manufacturing as the method to be used in space manufacturing [2 - 5].

The US consortium known as 'America Makes' is supported by NASA (www.nasa.gov) and is creating the initiatives of 'in-space manufacturing' with NASA leading the development on all aspects of manufacturing in space (https://www.americamakes.us/). Parallel development of manufacturing in space is taking place in the European Union (EU) as part of the strategic agenda of the EU focusing on additive manufacturing for the aerospace sector (http://www.rm-platform.com/) with a focus on materials and the circular economy (https://cordis.europa.eu/project/id/313781). ESA is funding in-situ additive manufacturing on planetary habitats such as the Moon and on asteroids using methods developed in the US.

**Conclusion & Significance:** The possibilities associated with manufacturing in space include planetary mining and manufacturing in orbit present many challenges that require an understanding of the physics of manufacturing and the integration of systems to minimize waste. The space environment allows the development of materials that cannot be made on Earth.

## Image


Figure 1. The Era of Long Duration Microgravity Materials Science Research. Image Courtesy of NASA.

## Recent Publications

1. Hirschberg C, Kulish I, Rosenkopf I, Sodoge T (2022) The potential of microgravity: How companies across sectors can venture into space. McKinsey Report: 1-7.
2. Volz M (2014) Materials Science in Microgravity. 3rd Annual ISS Research and Development Conference Chicago, Illinois.
3. Prater T, Werkheiser N, Ledbetter F, Timucin D, Wheeler K, Snyder M. (2019) 3D Printing in Zero G Technology Demonstration Mission: complete experimental results and summary of related materials modeling efforts. The International Journal of Advanced Manufacturing Technology. 101: 391-417.
4. Prater T, Werkheiser N, Ledbetter F, Morgan K (2018) In-Space Manufacturing at NASA Marshall Space Flight Center: A Portfolio of Fabrication and Recycling Technology Development for the International Space Station. Proceedings of the AIAA SPACE Forum, Orlando, Florida.
5. Prater T (2019) NASA's In-Space Manufacturing Project: Update on Manufacturing Technologies and Materials to Enable More Sustainable and Safer Exploration. Proceedings 70th International Astronautical Congress IAC-19.D3.2B.5. Washington, D.C.

## Photograph

## Biography

Prof. Mark Jackson is an endowed professor at Kansas State University's Aerospace and Technology Campus. He was educated in the United Kingdom at Liverpool, Oxford and Cambridge universities in mechanical engineering, materials science and condensed matter physics. His industrial experiences as apprentice, craftsman, technician, engineer, technical manager and director have served him well in his capacity as a researcher and inventor of new products and processes. He is a technical and management consultant and advises many companies on the development of new products, processes and the transfer of technology from the laboratory to the factory floor.

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