The Promise and Realities of Additive Manufacturing (3D Printing) in Space

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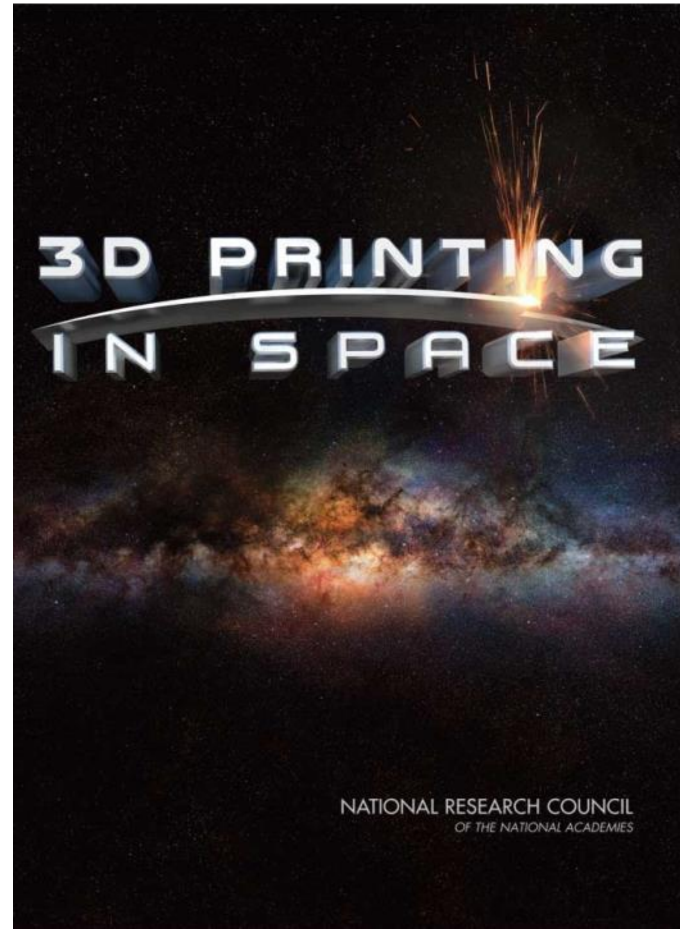
Overview

- Background of the study
- Background on additive manufacturing
  - Promise
  - Reality
  - Committee overall findings and recommendations

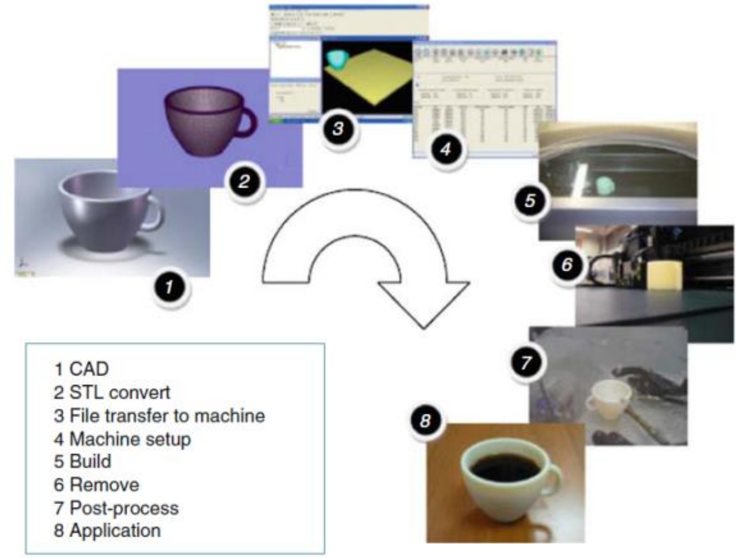
Background - NRC Study

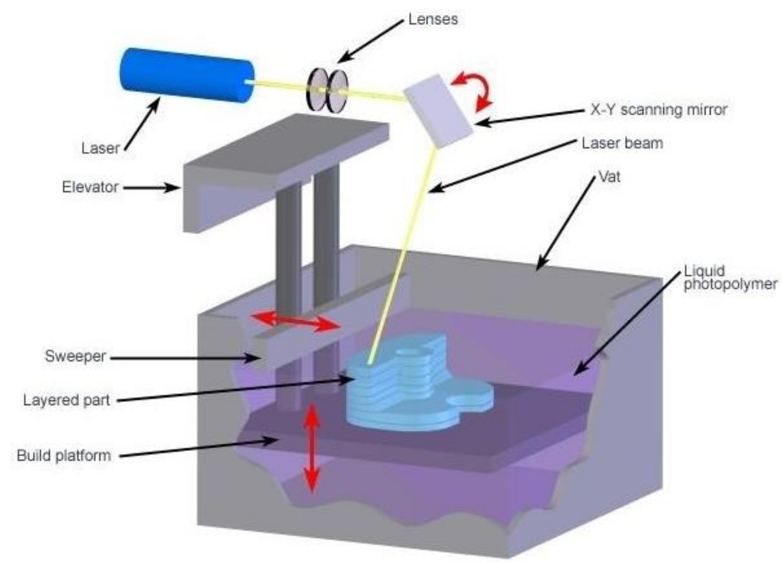
- Air Force Space Command and the Air Force Research Laboratory Space Vehicles Directorate and the NASA Science and Technology Mission Directorate, requested the US National Research Council (NRC) to
  - Evaluate the feasibility of the concept of space-based additive manufacturing of space hardware
  - Identify the science and technology gaps
  - Assess the implications of a space-based additive manufacturing capability
  - Report delivered in July
  - Printed in September



What is Additive Manufacturing?

- Additive manufacturing is the "process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies."
- Often called 3D printing
  - Typical materials are plastics, metals, some other substances
  - Technology has existed since the 1980s - primary change is that machines have become cheaper and range of uses has expanded
- Growing field - $3 billion in sales in 2013 (growing 76% from 2012 -2013) and expected to be $21 billion by 2020
- Expected to become a $200 b industry

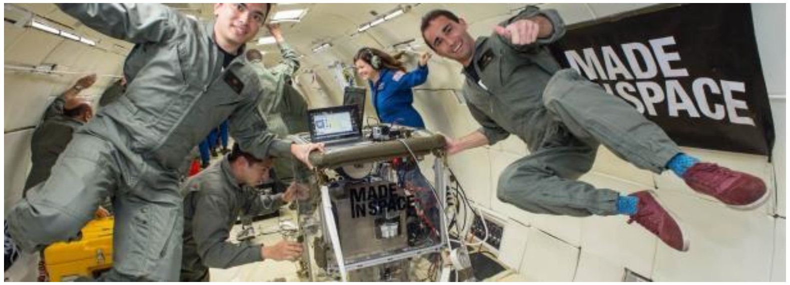




Additive Manufacturing FOR Space vs IN Space

- SpaceX's Super Draco engine includes a 3D printed combustion chamber made of Inconel created by direct metal laser sintering
- 3D printing happened terrestrially

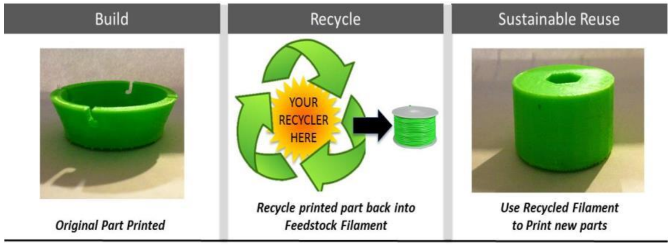
- A *Made in Space* 3D printer arrived at ISS September 23, 2014
- The 3D printer, 9½ inches wide and 14½ inches wide, will be installed in the Microgravity Science Glovebox
- 3D printing will happen ON the ISS – In Space

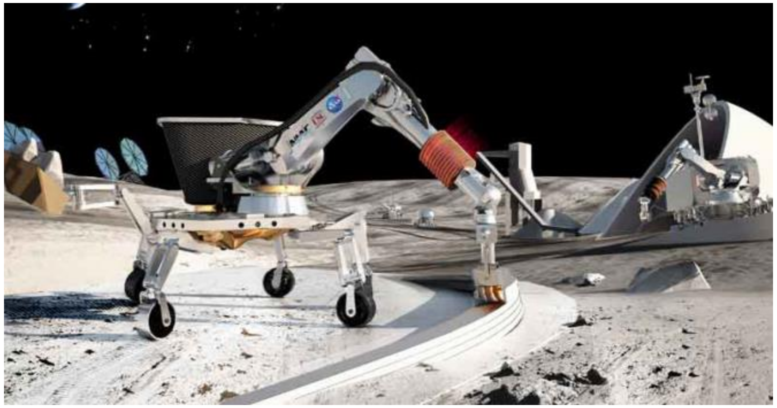


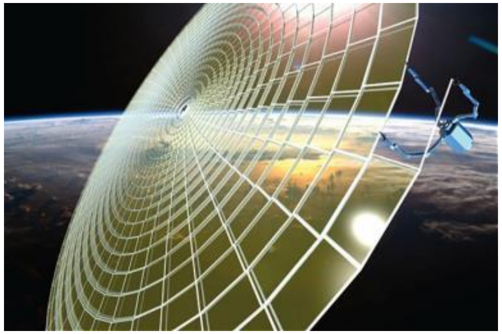
Committee focus was in-space

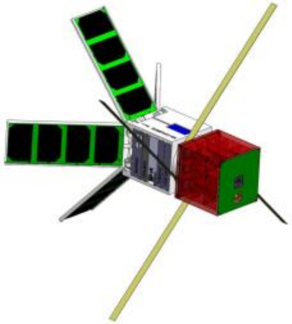
The Promise

- Manufacturing components
- Recycling
- Creating sensors or entire satellites
- Creating Structures Difficult To Manufacture On Earth Or Launch
- Using resources on off-Earth surfaces









The Reality - Challenges at Multiple Levels

NRC Report: http://www.nap.edu/download.php?record_id=18871

Terrestrial Challenges

- New materials
- Process modeling
- Precision and resolution
- Construction time
- Design tools and software

Infrastructure Related Challenges

- Manufacturing Platform
- Data and Telemetry
- Power

In-Space Challenges

- Gravity
- Vacuum
- Thermal Environment
- Quality, Verification, Validation and Functional Testing

ISS-specific challenges

- Safety

Free-flyer platforms

- Autonomy

Celestial Surfaces

- Suitability of *in situ* resources as feedstock

SUMMARY FINDINGS AND RECOMMENDATIONS

10 Findings in Five Categories

- **Additive manufacturing in space has great potential.** Space system configurations that are currently dominated by requirements to survive ground manufacturing, assembly, test, transport, and launch could be reexamined as AM capability becomes available, and *additive manufacturing might provide the means to transform space architectures*.

However, there are many technological and regulatory hurdles before such as vision could be achieved.

- **Terrestrial challenges remain unresolved.** Before moving additive manufacturing technology to the space environment, further development in several fundamental areas needs to be complete and well understood. These areas represent barriers to a wider use, even in a ground-based environment, and *preclude additive manufacturing techniques moving immediately to a space-based environment*.
- **Space related challenges magnify terrestrial ones.** The space environment (zero gravity, vacuum) poses additional constraints, and additive manufacturing is even more of a systems engineering and industrial logistics problem compared to additive manufacturing on the ground.
- **Technology not implementable without supporting infrastructure.** Supporting infrastructure and environment which are relatively straightforward and easy considerations on the ground (i.e. rent factory space, connect to the local power grid) are not simple for space - issues such as supply chain logistics, integrated processes, minimal human interaction, and quality control are more pronounced.

15 Recommendations for Air Force and NASA

- **Analysis**. Agencies need to do systems *and* cost benefit analyses (CBA) related to the value of AM in space. The analyses should not focus just on how AM could replace traditional manufacturing but how it can enable entirely new structures and functionalities that were not possible before. A specific area where a CBA would be helpful is in the manufacture of smaller satellites on the ISS.

- **Investment**. Targeted investment is needed in areas such as standardization and certification, and infrastructure. The investment should be strategic, and use workshops and other information-sharing forums to develop roadmaps with short and long-term targets.

- **Platforms**. Given the short life of the ISS, agencies should leverage it to the extent feasible to test AM and AM parts.

Recommendations (cont.)

- **Cooperation, coordination and collaboration**. Instead of stove-piped parallel development in multiple institutional settings, it is critical that there be cooperation, coordination and collaboration within and across agencies, sectors, and nations. It would be useful to develop working groups, conferences and leverage existing efforts such as the *America Makes*.

- **Education and training**. Agencies need to develop capabilities related to relevant fields such as material science and others that would be important for the development of the field of AM.

BACKUP SLIDES