The National Academies of
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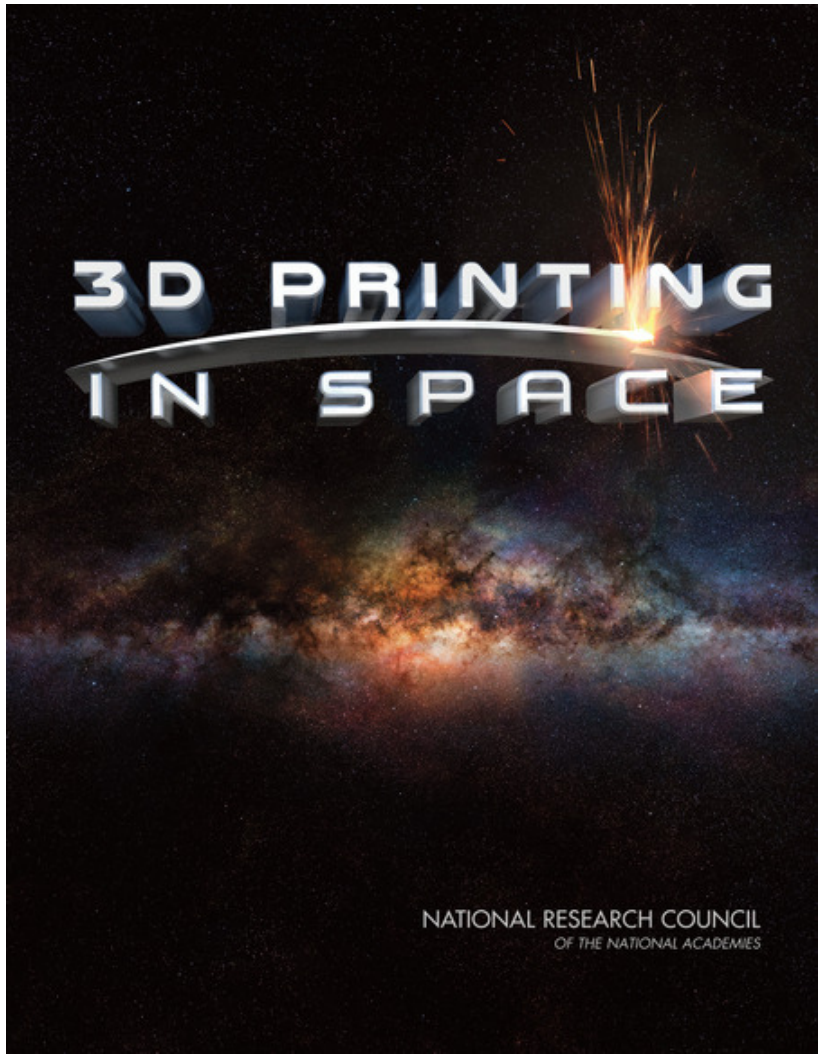
3D Printing in Space

Committee on Space-Based Additive Manufacturing

Presentation
July 2018



As requested by:

NASA

The Air Force Space Command

The Air Force Research Laboratory

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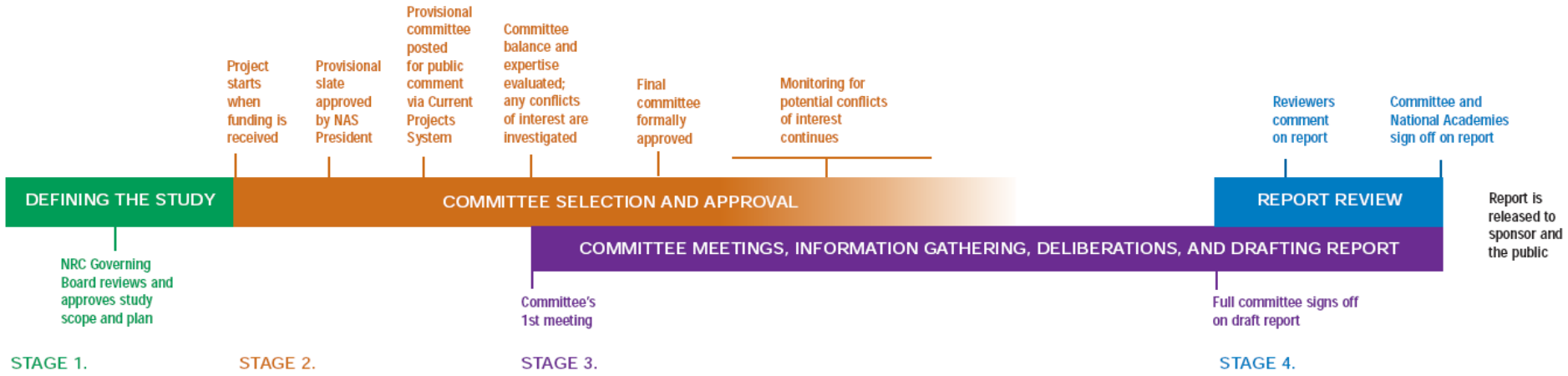
Our Process

The study process can be broken down into four major stages:

1) defining the study,
2) committee selection and approval,
3) committee meetings, information gathering, deliberations, and drafting of the report, and
4) report review.



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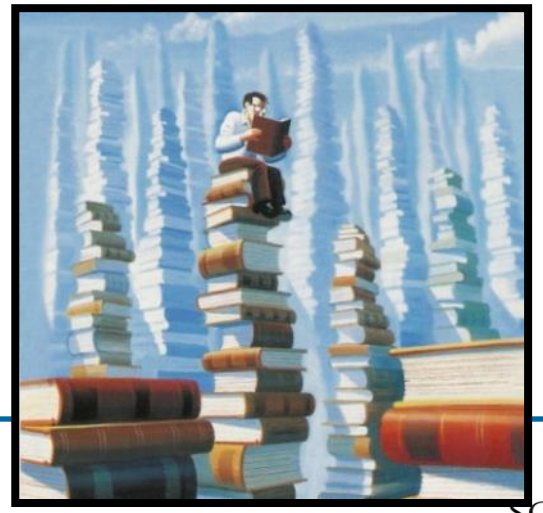

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Committee on Space-Based Additive Manufacturing

Aeronautics and Space Engineering Board
National Materials and Manufacturing Board
Division on Engineering and Physical Sciences

committee

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Statement of Task

- Assess the current state of additive manufacturing in the United States and worldwide (especially in the aerospace industries, universities, and national laboratories engaged in the design and manufacture of small satellites or respective subassemblies);

Statement of Task

- Characterize the future states envisioned by the aerospace industries, universities, and national laboratories with respect to additive manufacturing and aerospace systems;

Statement of Task

- Discuss the feasibility of the concept of space-based additive manufacturing of space hardware (including, but not limited to, a fully functional small spacecraft) that can conduct or enable missions of relevance to NASA, the Air Force, and/or the national security space communities;

Statement of Task

- Identify the science and technology gaps between current additive manufacturing capabilities and the capabilities required to enable a space-based additive manufacturing concept, including those gaps that current trends indicate may be closed with commercial investments in additive manufacturing and those gaps that are likely to require dedicated investments by the federal government.

Statement of Task

- Assess the implications that a space-based additive manufacturing capability would have on launch requirements (e.g., launching raw materials versus fully assembled spacecraft); overall satellite and payload designs; and inspace operations, such as possible reductions in mass and their implications for activities such as maneuverability.

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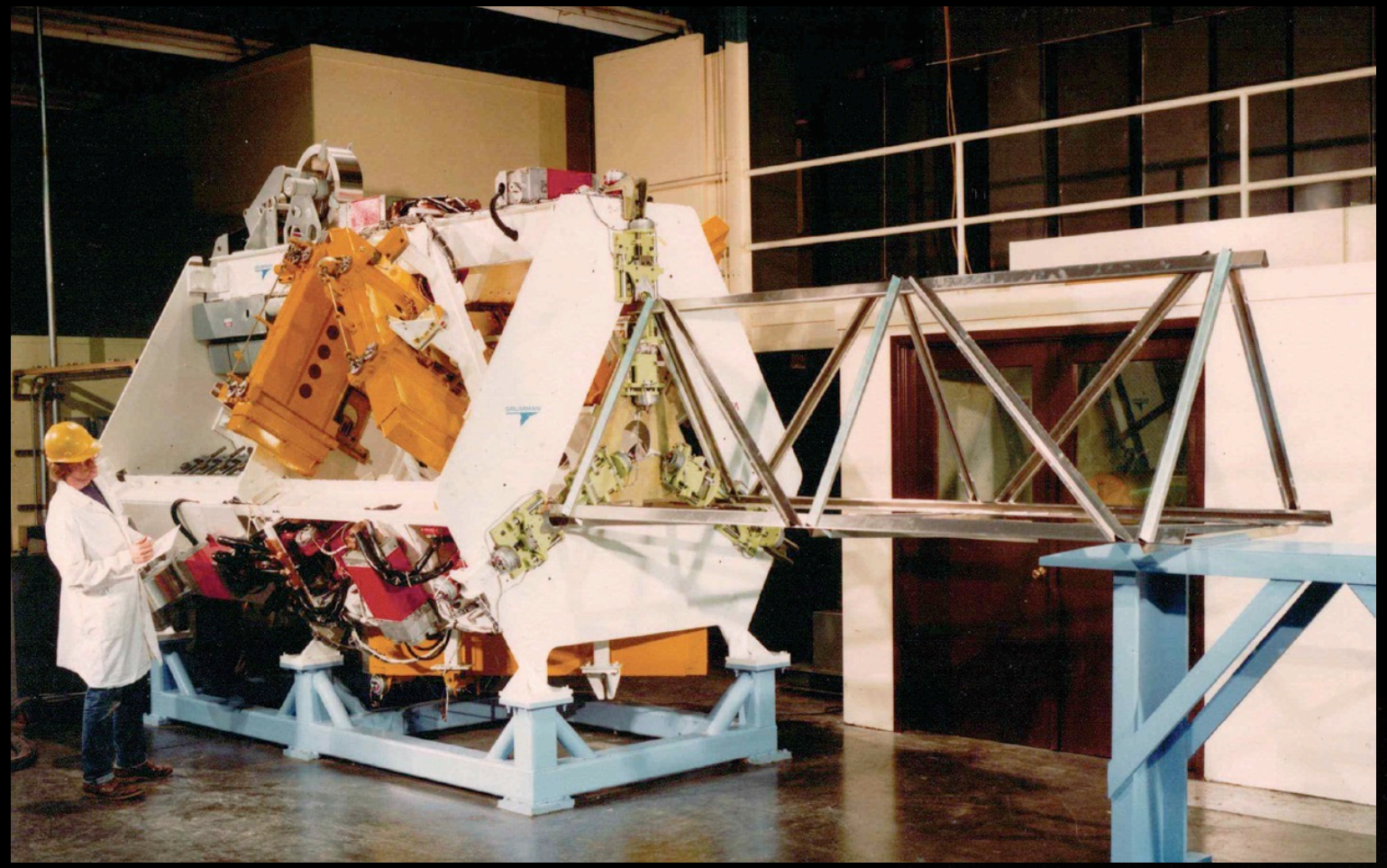
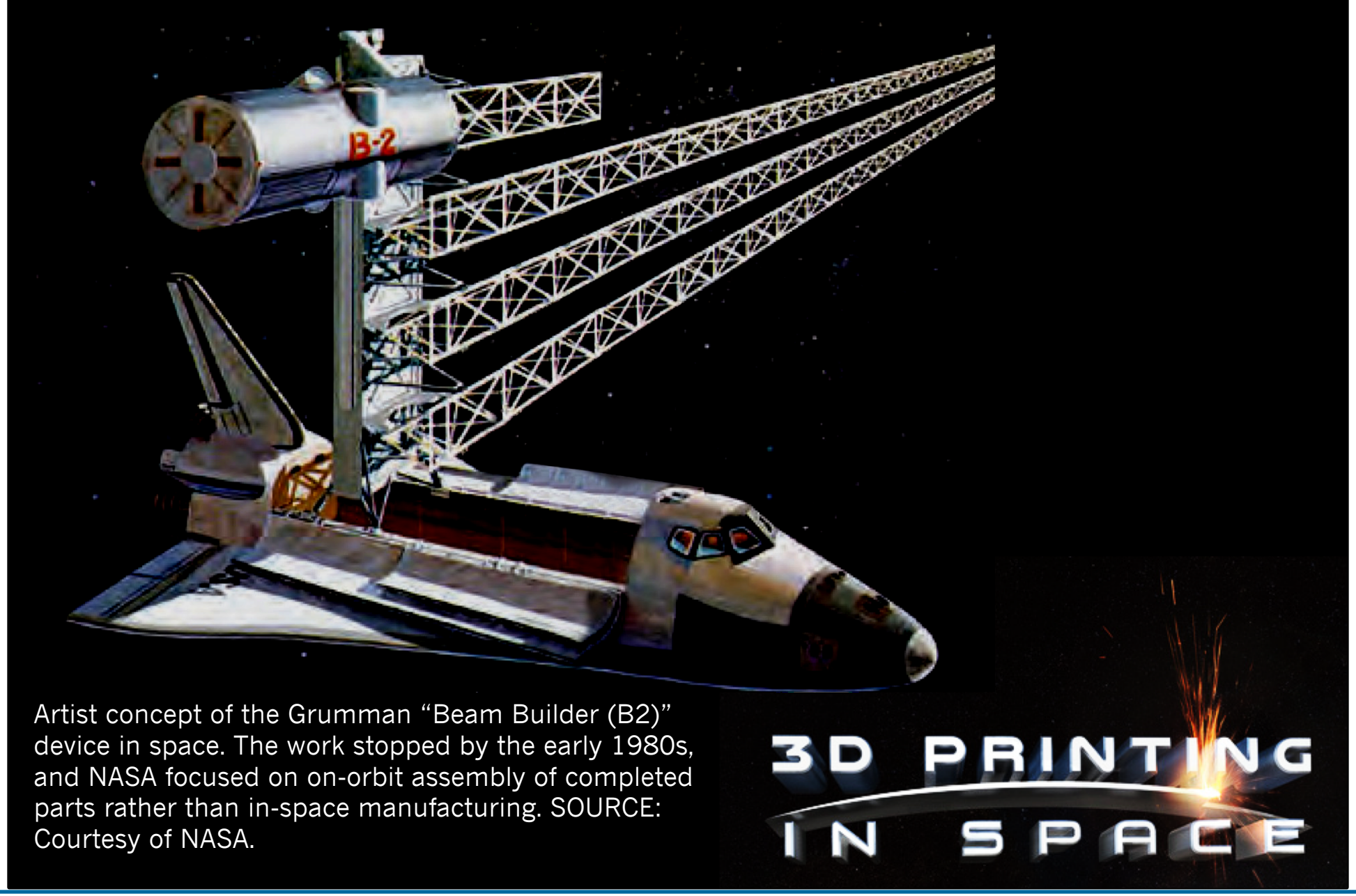
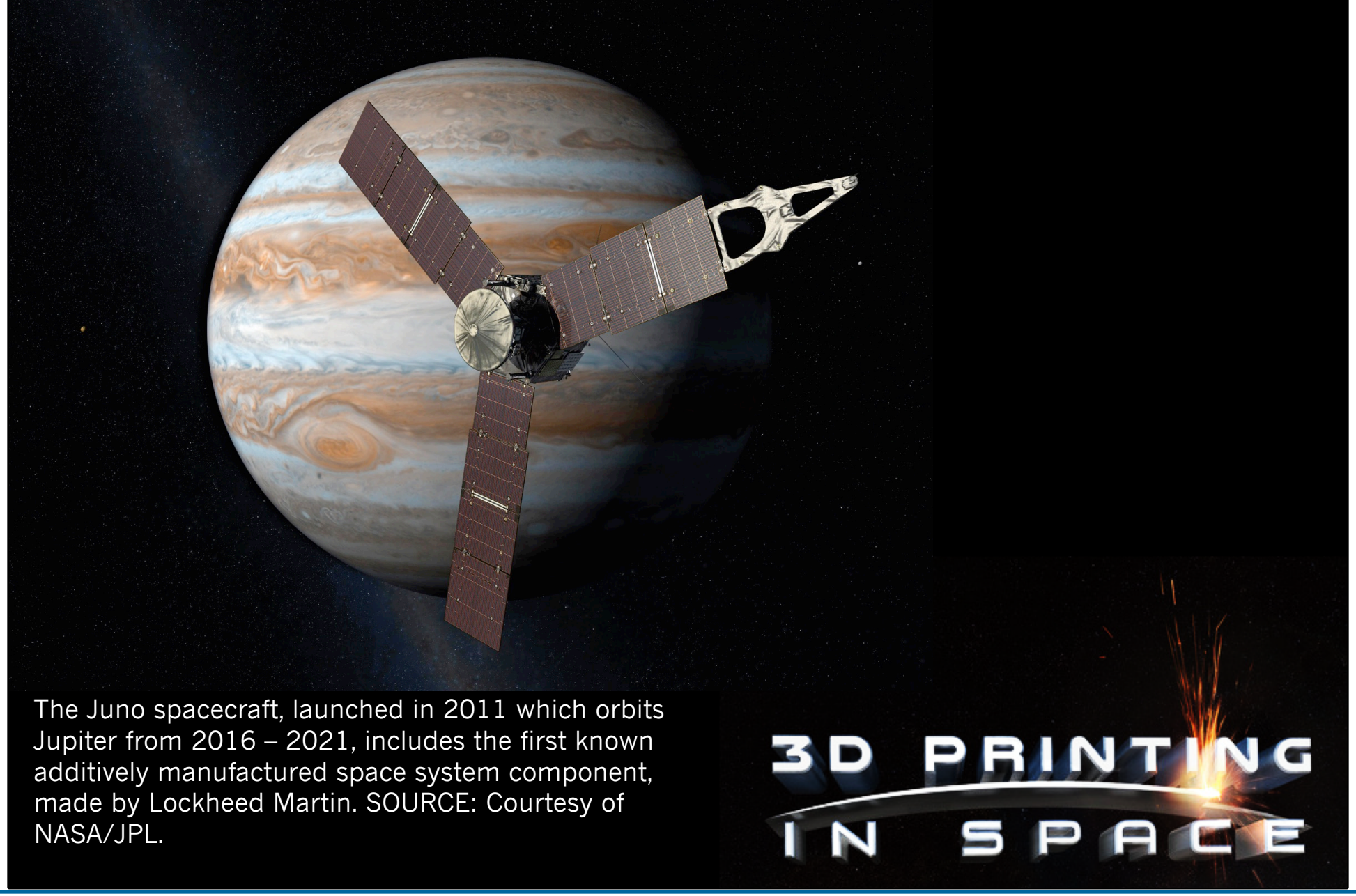


Grumman “Beam Builder” machine tested at Marshall Space Flight Center in the late 1970s. The machine used three rolls of rolled aluminum that it bent and then welded with cross braces. SOURCE: Courtesy of NASA.

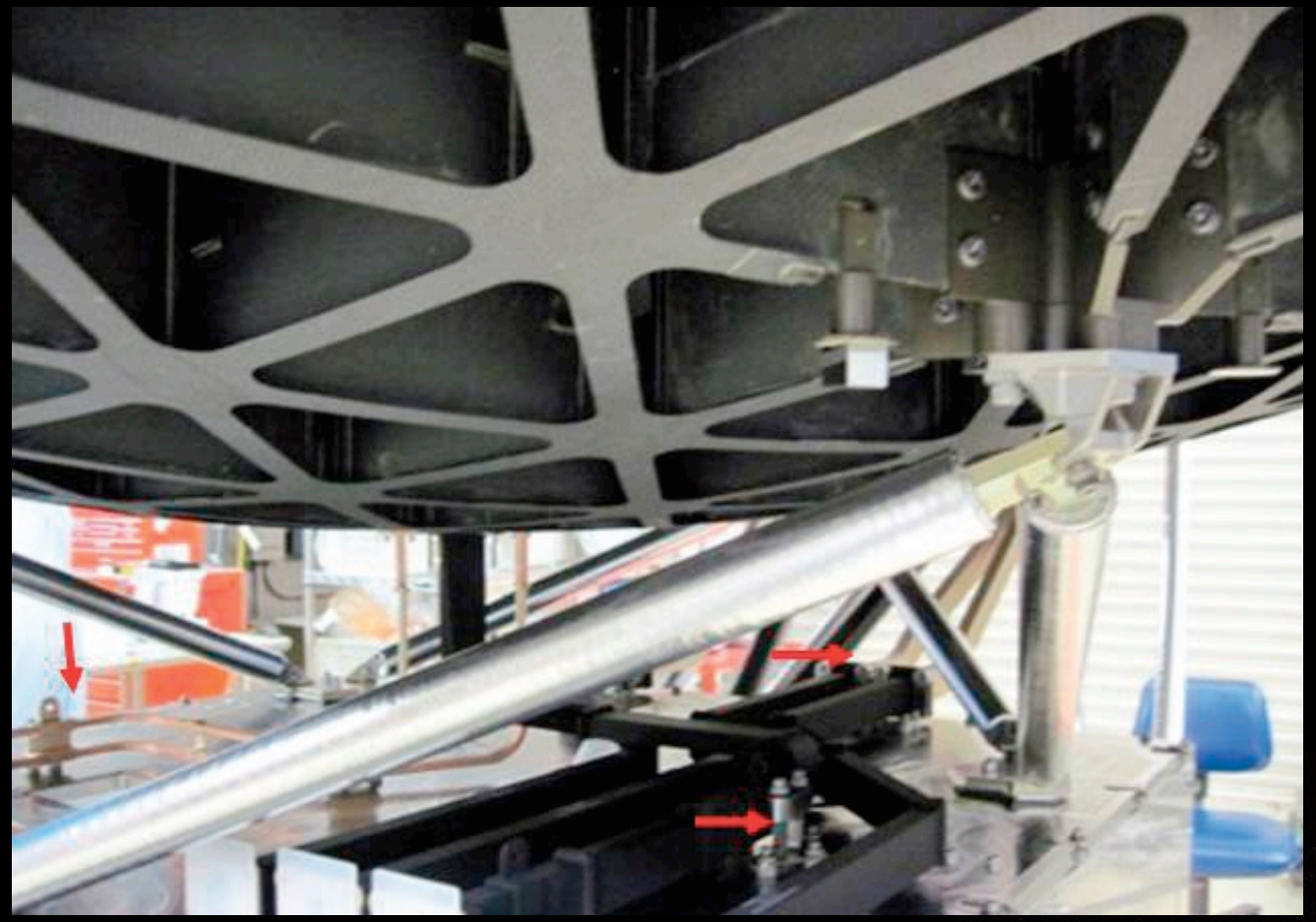
3D PRINTING IN SPACE



Artist concept of the Grumman “Beam Builder (B2)” device in space. The work stopped by the early 1980s, and NASA focused on on-orbit assembly of completed parts rather than in-space manufacturing. SOURCE: Courtesy of NASA.



The Juno spacecraft, launched in 2011 which orbits Jupiter from 2016 – 2021, includes the first known additively manufactured space system component, made by Lockheed Martin. SOURCE: Courtesy of NASA/JPL.



Additively manufactured waveguide brackets (shown by red arrows) installed on the Jupiter Juno spacecraft during
assembly. SOURCE: Courtesy of Lockheed Martin.

3D PRINTING IN SPACE

Identify the science and technology gaps

Recommendation: NASA should sponsor a space-based additive manufacturing workshop to bring together current experts in the field to share ideas and identify possible research projects in the short term (1-5 years) and medium term (5-10 years).

Characterize the future

Ground-based additive manufacturing is being rapidly developed by industry, and the committee therefore sought to determine **what aspects of spacebased additive manufacturing industry would not undertake on its own.**

The two most obvious are space-based robotics and automation and hybrid manufacturing in which two or more manufacturing processes work together, preferably in an automated way, in the space environment.

Because the most obvious applications are for human spaceflight and exploration and for military missions, the government cannot expect industry to invest in technology developments that do not have a clear path to profit.

Identify the science and technology gaps

There are some fundamental issues that industry will have to resolve before space-based applications can be derived.

A clear understanding of the **relationships** between the material and structural properties and their dependence on processing techniques needs to be established to ensure consistency in production.

The production process could also benefit from **standardization** of design software, file formats, and processing and equipment parameters, including developing closed-loop feedback control systems for the machines themselves.

Most importantly, a verification and **certification** methodology will have to be defined that guarantees the quality of the additively manufactured parts.

Recommendation: NASA and the Air Force should jointly cooperate—and possibly involve additional parties, including other government agencies as well as industry—to research, identify, develop, and gain consensus on standard qualification and certification methodologies for different applications. This cooperation can be undertaken within the framework of a public-private partnership such as America Makes.

The Possibilities

NASA recently extended the lifetime of the ISS to 2024. The space station's lifetime could possibly be further extended. Nevertheless, this represents a finite opportunity for further development of the technology in an ideal environment, when human assistance is possible.

Recommendation: NASA should quickly identify additive manufacturing experiments for all areas of International Space Station (ISS) utilization planning and identify any additive manufacturing experiments that it can develop and test aboard the ISS during its remaining years of service and determine if they are worthy of flight. NASA currently has methods for providing research grant funding for basic research on additive manufacturing. The agency should closely evaluate funded research options to determine which would allow the most rapid transition of additive manufacturing to the ISS.

Implications NASA

Recommendation: NASA should convene an agency-wide space-based additive manufacturing working group to define and validate an agency-level roadmap, with short- and longer-term goals for evaluating the possible advantages of additive manufacturing in space, and with implications for terrestrial additive manufacturing as well. The roadmap should take into consideration efficiencies in cost and risk management. NASA should build on the considerable experience gained from its Space Technology Roadmaps. The space-based additive manufacturing roadmap objectives should include, but not be limited to the following:

• Developing goals for using the technology to assist the agency in meeting its key missions, covering all appropriate mission directorates, especially long-duration human spaceflight and planetary operations, which would require defining, understanding, evaluating, and prioritizing the direct and supporting technologies for autonomously or minimally attended space-based additive manufacturing, and robotic precursor and free-flyer missions;

• Identifying flight opportunities, such as on the International Space Station, during its next decade of operations,

• Targeting the full technology-development life-cycle and insertion strategies through 2050, aligned with target agency missions, for all appropriate mission directorates, and related collaborations; and

• Ensuring that support for incremental advances to address the technical challenges is supplemented with support for activities related to reaching the full potential of additive manufacturing.

Implications Air Force

Recommendation: The Air Force should establish a roadmap with short- and longer-term goals for evaluating the possible advantages of additive manufacturing in space. The Air Force should build on the considerable experience gained from other Air Force technology development roadmaps. The space-based additive manufacturing roadmap should include, but not be limited to the following:

- Developing goals for using the technology in key Air Force missions, especially for autonomously or minimally attended, space-based additive manufacturing and free-flyer missions;
- Identifying flight opportunities, including those on non-Air Force platforms, such as the International Space Station, during its next decade of operations; and
- Targeting the full technology-development life-cycle and insertion strategies through 2050, aligned with Air Force missions, and related collaborations.