3D Printing in Space: The Next Frontier

This briefing is an executive summary of a webcast of the same title on July 16, 2014, sponsored by Stratasys.

Introduction

NASA has a long-term strategy for In-Space Manufacturing that includes fabricating components and equipment on demand for human missions to the Moon, Mars, and beyond. To support this strategy, NASA's Marshall Space Flight Center (MSFC) and Made In Space, Inc. have developed the 3D Printing In Zero-G Technology Demonstration for the International Space Station (ISS). The experiment will be the first machine ever to perform 3D printing in space.

The technology to produce parts on demand, in space, offers unique design options that are not possible through traditional manufacturing methods, and offers cost-effective, high-precision, low-unit, on-demand manufacturing. In addition to the obvious benefits of disrupting the traditional and costly supply chain for space missions, there is the value of being able to design and build a part in the microgravity environment, thus removing the standard structural constraints due to launch loads. This opens up a whole new design arena: designing for zero-g structures.

The 3D Printing In Zero-G experiment will serve as the enabling first step to realizing an additive manufacturing, print-on-demand "machine shop" for long-duration space missions.

Why 3D Print?

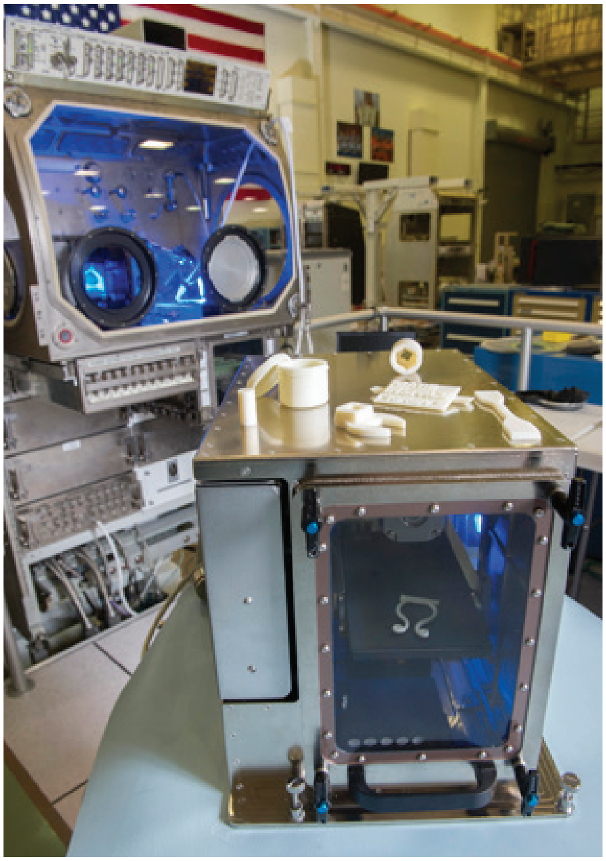
Why use additive manufacturing (AM) in space? Right now, it's a very slow and very expensive process to get things to space. Everything that has to go up has to be over-designed just to survive launch, which is only 10 minutes or less of the overall mission. There are volume restrictions, so everything must fit within the launch vehicle. Getting anything into space requires a very large test plan to ensure it can survive these events. It's very inefficient, very slow, and if the part is not critical or needed immediately, it could be six months to a year or more before something can be sent to space. So how can we speed up the process?

Some of the reasons NASA chose 3D printing were obvious in terms of space exploration past the International Space Station. A study was done that documented every failure of every part, whether a small part or a full system, and how long it took to correct the problem. Was a new part flown up, or was an on-orbit solution found?

The study results showed that 82% of the failures can be considered preliminary candidate application areas for additive fabrication and repair technologies. For the failed non-critical items, the repair time minimum was six months, primarily due to the launch cycle. Sometimes failures are never corrected; it's not something that can be fixed, even with a new part.

All the parts that tend to break are not designed with additive manufacturing in mind. This is a lifecycle, and the more parts are designed with additive manufacturing in mind, the more opportunities

The 3D printer will operate inside the Microgravity Science Glovebox, a rack that provides a level of containment and filtration.



The 3D Printer in Zero-G Technology Demonstration payload is seen here undergoing final flight certification testing at NASA's Marshall Space Flight Center. Designed and built by Made In Space, it will be the first 3D printer to fly in space. (Photo by Emmett L. Given/NASA MSFC)

there are to implement AM. It's a mentality and paradigm shift from where NASA is today, and it is a meaningful one.

So what happens when design methodologies change to incorporate this new paradigm? The first step is understanding that there is an overly constrained supply model. NASA has worked very hard to decrease the cost of launch to space, but the agency has never been able to move that number; it remains at $10,000 per pound launched. Being constrained by this supply model of launching every single part that's needed, NASA increases risk and decreases efficiency, all while paying considerable cost.

So when NASA looks at enabling exploration missions — whether it is to the Moon, Mars, or an asteroid — it is not a "nice to have" in terms of the capability to make what's needed. It's a critical enabler.

The space station will be operating until 2020, and possibly until 2024 or beyond. There is much more science being done on the station, and year-long missions are scheduled. Even though NASA has done a remarkable job over the past 12 or 13 years of the space station life, ways to increase efficiency and decrease cost must be investigated.

From the Ground Up

3D printing is a method of building objects layer-upon-layer. There are a variety of different methods to do this, and NASA and Made In Space are focusing in the immediate future on deposition fabrication, or fused deposition modeling (FDM). Parts are taken from three-dimensional CAD drawings, converted into codes that the printers can interpret, and then built. The philosophy and science of 3D printing has been around for about 30 years.

The overall goal of Made In Space was to take additive manufacturing devices that existed and modify them for space. Anything sent to space needs a completely different set of requirements because of the environment. Made In Space had the machines and wanted to see what had to change on them, then modify and fly them.

Made In Space initially started a zero-G flight campaign in 2011 and completed zero-G, Martian-G, and Lunar-G flights, accumulating more than two hours of microgravity time. The objective was to test commercial machines and their own machines to determine the effects of reduced gravity on the machines.

The parabolic flights took place on a converted 727 commercial airliner. Once the plane gets to altitude, it pitches over, and during that pitch-over time, passengers are weightless. The plane goes from a high angle of attack to level, causing weightlessness until the pull-up starts. There are about 30 seconds of weightlessness.

It was quickly determined that the things being modified on these devices were substantial in nature. The company realized that building it from the ground up would be easier than modifying a machine to make it work. In fact, a machine would have to be modified twice — once to work perfectly in a reduced-gravity environment, and a second time to get the same equipment to launch to space.

In the test flights, Made In Space gathered technical information on how to build the printers to work in the microgravity environment. Through the test flights, design methodologies were developed from the results, enabling the company to build up the technology. A prototype of the printer was tested, and worked as expected.

The 3D Printing in Zero-G Experiment is a precursor to a follow-on permanent commercial printer being built by Made In Space that will be larger with a larger print volume, and will be able to print other materials. It will have more autonomy and more sophisticated software.

The 3D printer technology demo is about the size of a small microwave oven. For the technology demonstration, the printer will operate inside the Microgravity Science Glovebox, a rack that provides a level of containment and filtration. The printer requires very little astronaut interaction. Files will be sent from the ground to the printer. Everything can be done from the ground except setting the printer up and removing the part from the print tray between prints. There are two windows that will have high-definition video cameras aimed at the print tray during the print, so the layers will be visible as they're being printed, providing immediate feedback.

The initial parts will be flown back to Earth for detailed ground analysis. NASA will determine how quickly it can go from uplinking a print file to actually having the part completed. The first series of prints will be mechanical property test articles — things such as tensile, compression, torque, range, flexure, and vertical column for mechanical property testing. These items are the crux of why NASA is doing this.

A New Initiative

NASA has implemented an In-Space Manufacturing Initiative with three platforms on how it is approached. The first is the Earth-Based Platform for technologies that may be a lower Technology Readiness Level (TRL) — things that can be tested on the ground before implementing them in space. This includes certification and inspection of parts. Looking at data on using different feedstocks on different printers, or even different lots of the same feedstock, there are differences in the print quality and reliability between printers and feedstock. So it's important to understand that in terms of certifying a part for use in space.

There are several other areas such as printable electronics. NASA won't reinvent the wheel — it's already happening on the ground, and there are several technologies being developed and tested. NASA wants to leverage commercial technologies and development, spending their very limited funds on how to adapt them for in-space uses.

Second is the International Space Station Platform. The space station is the only laboratory platform of its kind in the universe. The parabolic flights made by Made In Space to test the printers provided the first indication that the process would work in microgravity. For the printer, the ISS is the only platform available to perform a proof-of-concept demonstration to show that additive manufacturing works the same way in microgravity as it works on the ground.

Other areas NASA will be exploring as part of in-space manufacturing include a recycler. They are looking at taking a small plastic part printed on-orbit and recycling that into the raw feedstock, which would be a huge step toward true sustainability in space. Obviously, there are immediate benefits from printing in space, such as not having to launch as many spares and backups. With a recycling capability, there will be a one-to-one sustainable chain.

Third is the Planetary Surfaces Platform for exploration missions, and this is centered on in-situ resources; how the native regolith can be used for synthetic biology. Other technologies include additive construction — large-scale printers that can print buildings, structures, runways, landing strips, and storage shelters.

NASA has a vision of how to get there that starts with the 3D Zero-G Technology Demonstration. NASA has done everything that can be done on the ground and extensive parabolic flights, but the necessary next step is to use the ISS with a consistent microgravity environment to show that the parts printed in space are equitable to those printed on the ground.

Authors/Presenters

Niki Werkheiser is the NASA Project Manager for the 3D Printing in Zero-G Technology Demonstration, which will launch on SpaceX-4 and be the first 3D printer to operate on the International Space Station. She is developing the Roadmap and Implementation Plan for NASA's In-space Manufacturing Vision, which will be critical to enabling Exploration missions. Previously, she served as the Project Manager for NASA's Ares Crew Safety and Reliability Office. Ms. Werkheiser spent the majority of her career in NASA's Space Shuttle and International Space Station Programs Payload Offices where she designed, developed, integrated, and operated multiple NASA payloads.

Michael Snyder is Director of Research and Development and Lead Engineer at Made In Space, and is heavily involved in the research and analysis of additive manufacturing techniques for use in space. He has tested experimental additive manufacturing machines in a simulated microgravity environment in NASA's Reduced Gravity Office supervised flights aboard the G-Force One Aircraft. Mr. Snyder is currently the Principal Investigator for two NASA-funded contracts for in-space additive manufacturing. He is the current secretary of the American Institute of Aeronautics and Astronautics' Space Colonization Technical Committee, and serves on the Executive Committee of the National Space Society.

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