# Custom 3D Printers Revolutionize Space Supply Chain

## NASA Technology

Like a desert caravan, a space flight crew has to bring with it everything it will need over the course of its journey into an utterly barren environment. This has always meant allotting room for every gyroscope or astrolabe, every LED housing or oil lamp. In space travel, not only is payload capacity at a premium, but these objects also must be made to withstand the g-force and jarring vibrations of liftoff.

All of that is about to change.

In January of 2015, aboard the International Space Station (ISS), Made In Space Inc. and NASA's Marshall Space Flight Center plan to carry out the first additive manufacturing technology demonstration performed in space, using a customized 3D printer that the company developed over the previous three years with NASA support through the Small Business Innovation Research (SBIR) program.

"No one's ever done this before, where supplies are actually created in space," says Niki Werkheiser, NASA's project manager for the 3D Printing in Zero-G Technology Demonstration.

"You've got to imagine how cool this is," she says, noting that the biggest constraint on a space mission's distance and duration is the limit to what can be carried and the lack of a supply chain, making in-space manufacturing a necessity for any manned, interplanetary exploration. "We're using the space station as a test bed to test the technology we know we'll need on exploration missions. We'll absolutely need this."

That was just what the founders of Made In Space, located at Ames Research Center in Moffett Field, California, had in mind when they started the company in 2010 after meeting at Singularity University, also located at Ames, says Made In Space spokesman Grant Lowery. "We saw the supply chain as the biggest problem facing space travelers," he says. "With the rise of the commercial space industry, there's going to be a growing demand for


Made In Space Chief Strategy Officer Mike Chen, left, and Chief Technology Officer Jason Dunn test the company's prototype for a space-ready 3D printer in simulated microgravity aboard Zero G Corporation's modified Boeing 727 in 2013.


In the Made In Space "clean room," Chief Technology Officer Jason Dunn pulls a sample part from the company's prototype for a 3D printer that can operate in microgravity, as lead engineer and director of research and development Michael Snyder looks on.

the ability to manufacture out there. We think it will save time, money, and logistical difficulty."

In 2011, through NASA's Flight Opportunities Program, the company tested several existing 3D printers in simulated microgravity aboard Zero-G Corporation's modified Boeing 727 and found them to be ill-suited to a weightless environment.

"Everything on Earth is built with gravity assumed," Lowery says, explaining that the machines' builders took for granted that certain parts would rest on others, for example.

Funded by an SBIR contract through Marshall, the Made In Space engineers set about building a model that was gravity-independent. It also had to be ruggedized to survive liftoff, and the builders couldn't allow for any off-gassing that would contaminate a hermetic atmosphere such as that found onboard the ISS. Machinery for use in space also has to take into account a lack of natural convection due to the lack of gravity, meaning air has to be forced to circulate.

"Those are some of the areas where NASA was able to provide some insight," Werkheiser says.

"We've benefitted from the partnership, and they've been wonderful in offering their expertise," Lowery says of the NASA team the company has worked with.

## Technology Transfer

In early 2013, Made In Space was awarded a Phase II SBIR to develop a commercial model to be permanently installed aboard the ISS, as well as a separate Phase III

contract to build the prototype that was tested aboard the space station in 2014. The prototype was first tested aboard Zero G's plane, which flies in parabolic arcs to create intervals of weightlessness, but these periods were too short to adequately prove the printer's effectiveness in consistent microgravity.

That problem is being addressed by flying the prototype, about the size of a small microwave, to the ISS for a demonstration in space. There, it will create more than 30 objects, including calibration coupons and tools such as a crowfoot wrench. Most will be based on files loaded on the machine before launch, but others will be uploaded to the printer from Earth while it is in orbit.

NASA has already identified a list of tools, parts, and other objects that are commonly lost or broken on the space station, including structural items, torque tools, containers, clips, and many others, from the crucial and complicated to the mundane. Lowery says crewmembers told the company one simple set of objects often in demand aboard the station is silverware.

"The crew gets really excited about this," Werkheiser says, noting that astronauts often have to wait months for simple parts that could be printed in a matter of minutes.

Lowery says a NASA study estimated the device would be able to print about 30 percent of the small parts and tools aboard the space station, and Werkheiser noted that even large items could be designed as a set of smaller parts that fit together.

The prototype prints objects from acrylonitrile butadiene styrene plastic, the same material that standard LEGO blocks are made of. Its successor, which will be slightly larger, will print with a variety of materials, and Werkheiser says NASA would eventually like a machine that can print metal parts. She says the team is also working on the capability to convert printed products back into the feedstock, essentially recycling the printer's output.

Lowery points out that with a 3D printer, the Apollo 13 crew could have easily recreated the carbon dioxide


The prototype for a 3D printer capable of operating in microgravity, created by Made In Space with the help of a couple of Small Business Innovation Research contracts with NASA's Marshall Space Flight Center, is slightly smaller than the one the company will create for installation aboard the International Space Station.

scrubber they needed, rather than adapting an ill-fitted scrubber with spacesuit hose and duct tape. "Now you can actually custom-make the part or piece or tool you need," he says.

## Benefits

Under the agreement for use of the commercial 3D printer on the ISS, Made In Space will own the machine, and NASA will be a customer paying to use it. "We want commercial companies to make the things we need," Werkheiser says.

However, she says NASA will be far from the only customer. "It's actually a business in space."

Much like NanoRacks, the company that built and owns 36 modular laboratories aboard the ISS and counts NASA and a host of other entities, including universities, foreign space agencies, and private companies, among its paying customers (*Spinoff* 2012), Made In Space expects broad appeal to the idea of manufacturing products in space. Indeed, NanoRacks' chief technology officer has been an advisor to the Made In Space team, and the final printer will be located with the NanoRacks equipment in the station's US lab.

With the ability to upload design specifications to the printer from Earth, customers "can essentially email their hardware to space," Lowery says.

"We're just trying to wake people up to the range of possibilities that exist because of this capability," he says, adding that even the company isn't sure exactly how wide that scope might turn out to be, in terms of commercial and research possibilities.

Lowery says Made In Space has already spoken with a number of companies, universities, government agencies, and even artists who are interested in the ability to easily create objects in space and even launch them into low orbit from the ISS.

A major application of the technology, as Lowery sees it, will be the creation and deployment of nanosatellites—little shells around four inches in diameter that can carry any number of technologies or experiments. "You could print the satellite in a matter of hours, slip an electronics board into it, toss it outside the space station, and you've got a satellite," he says.

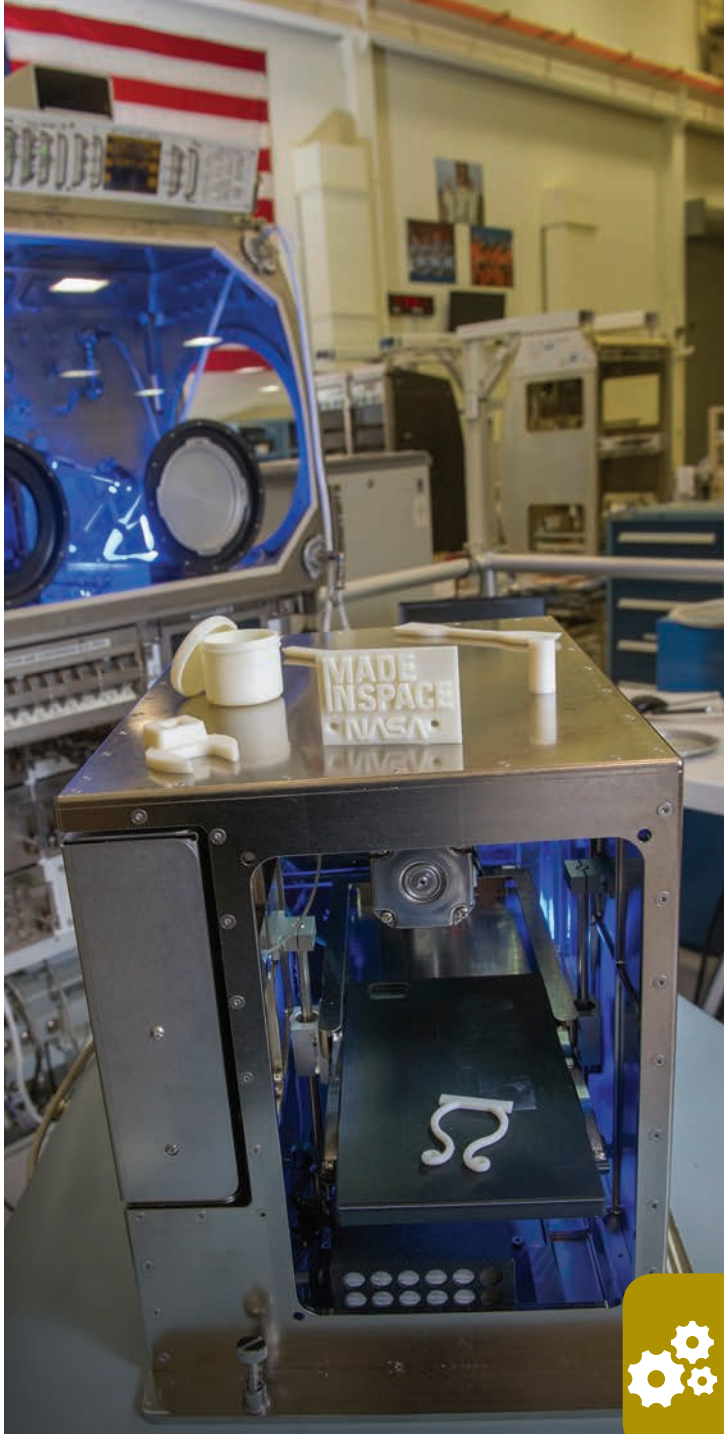
NanoRacks already has a system for nanosatellite deployment from the space station and has flown scores of the little packages into space on various rocket launches. NASA's CubeSat Launch Initiative has helped to find room in rocket payloads for nanosatellites being used by a variety of entities for research and educational purposes.

The company's 3D printer could drastically alter the CubeSat initiative. While the satellites' cargo often would still have to be physically transported into space, payload logistics and size limits would present far fewer constraints.

Werkheiser notes that nanosatellites are already being made with 3D printing on the ground and are becoming widely used for defense, communications, education, research, and other applications. "I really think it's going to be a big business," she says.

She says the technology will also find uses on Earth, and military services have already expressed interest in a 3D printer capable of micro-precision in its output, ruggedized to withstand physical hardship, and built to meet the highest safety ratings. A durable, reliable 3D printer would be especially useful in a submarine, in the desert or "anyplace where you're in a remote area and you're dependent on the parts you have with you," Werkheiser says.

She says this technology, which will make remote areas more habitable on Earth and in space, for astronauts and for others, and this partnership are prime examples of what can come from cooperation between NASA and the business community. "The SBIR process has been excellent for leveraging the capabilities of small companies to meet NASA's objectives, and we can't wait to see what comes next." ❖




Made In Space's prototype for a space-ready 3D printer is shown with some of the products the final model might produce aboard the International Space Station.