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A wildfire's newest enemies

Commercial airtankers take shape with no time to waste

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Just hit print

In the late 1950s and early '60s, a manufacturing revolution unfolded in what we now call Silicon Valley. NASA wants to work a similar magic, this time in the area of additive manufacturing and 3D printing. Edward Goldstein, a former NASA lead writer, looks at the research and the promise.

3D printing with plastic or metals could enable far bolder space exploration missions, or the technique could go down as a novel but largely impractical idea. In NASA's view, there's only one way to find out. The agency is funding research to test the feasibility of this and other additive manufacturing techniques for making aerospace components on Earth, aboard the International Space Station, in open space, or on the moon or Mars.

NASA has always been a driver and user of new technology. It was NASA's specific need for advanced integrated circuits for the Apollo moon missions that set the stage for the boom in circuitry production in Silicon Valley. Some of the 3D work is playing out there in support of the broader Obama administration-sponsored "America Makes" manufacturing initiative. Additive manufacturing refers to making 3D objects by laying down material a layer at time according to a digital blueprint. The research reflects the agency's renewed focus on technology development under administrator Charles Bolden. When NASA's Constellation human spaceflight program was on the books, NASA "just didn't have the funding or resources to be looking at lower level technologies," says Andrew Keys, the chief technologist at NASA's Marshall Space Flight Center.

With so many 3D projects underway, the National Research Council's Aeronautics and Space Engineering Board has launched a study to explore additive manufacturing for space applications. "We're specifically looking at the possibilities as well as the technical challenges of taking this technology out into space," says Dwayne Day, the board's senior program officer. "I think one of the things that we are learning is that for some applications this is a promising technology, but it's promising within a somewhat limited range. It's never going to be a complete re-

Made in Space team members monitor 3D printers aboard a Boeing 727 modified by Zero Gravity Corporation to simulate microgravity.

NASA

placement for traditional assembly and integration in space."

Parts made in space

3D printing is scheduled to be tried aboard the space station later this year when a SpaceX Dragon cargo module arrives in August with equipment for a demonstration called the 3D Printing in Zero-G Experiment. The printer was built by Made In Space, a 24-person company in Mountain View, Calif., in cooperation with NASA Marshall under a Small Business Innovative Research contract. Astronauts will use the station's Microgravity Science Glovebox to initiate the printer's production of simple plastic objects, such as wrenches or specimen containers. The printer will use extrusive additive manufacturing, in which layers of polymers or other materials are laid down according to computerized 3D patterns. They'll be returned to Earth for inspection alongside parts manufactured on the ground.

"Our goal is to help people build experiments, fix things that need fixing and give a really good go at exploration," says Michael Snyder, Made In Space's lead de-

by Edward Goldstein

sign engineer and director of research and development. If all goes as planned, a more sophisticated 3D printer will be carried to the station in 2015, and it will become "a full-time facility that's open to anybody to make anything they want on the station," Snyder says. That could mean parts to fix or upgrade space station experiments, or parts made for educators and researchers who want to try the technology.

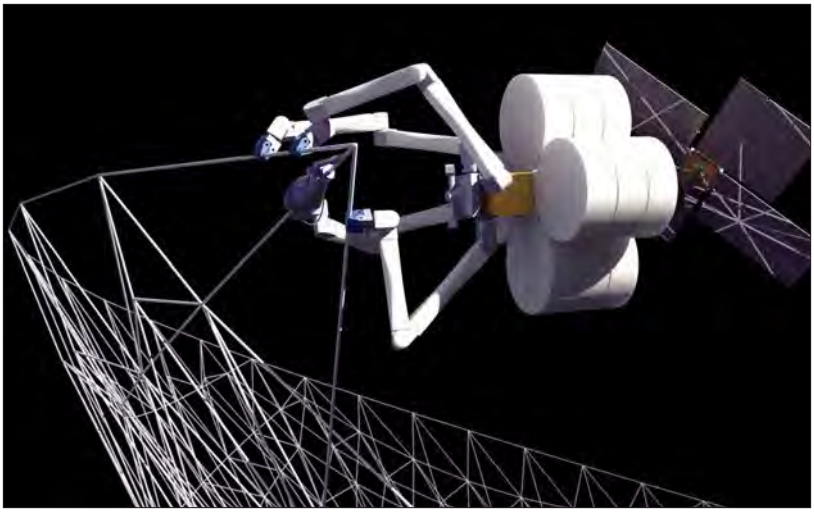
The Replicator could be here.

NASA is watching progress under a small business grant awarded in May 2013 to the Systems and Materials Research Consultancy in Austin, Texas, to study the feasibility of 3D printing for making food in space. A likely first menu item: pizza.

The space station isn't the only option for additive manufacturing in space. Tethers Unlimited, Inc., of Bothell, Wash., has been working since 2012 under a NASA Innovative Advanced Concepts contract to develop a technique for making multifunctional spacecraft structures in open orbit. In March, TUI received a NASA small business contract to continue developing its proposed spaceborne "Trusselator," a device that would automatically extrude layers of material to form lightweight carbon fiber truss structures. These would be robotically assembled into solar arrays, antennas or other components. The Trusselator is part of the company's plan to launch what it calls "self-fabricating satellites." Raw materials would be launched, and then the Trusselator would get to work forming structures out of it. A gangly SpiderFab robot would crawl across the pieces to attach them together. The technique is described in the September 2013 AIAA paper, "SpiderFab: An Architecture for Self-Fabricating Space Systems."

TUI's CEO and chief scientist Rob Hoyt says the approach could give spacecraft designers a new level of freedom: "We're focused on being able to create space system components that are much bigger, much higher performance than could possibly fit into any of the available launch shrouds," he says. "We hope to be able to do an initial [on-orbit] demonstration mission within a couple years."

Construction help: Tethers Unlimited's SpiderFab robot, seen here in an artist's rendering, would crawl across large parts made in space, attaching them to each other to form larger structures.



Tethers Unlimited

The challenge of metals

Given the strength and temperature limitations of plastics, other researchers hope to show the feasibility of 3D printing with metal. It won't be easy. On Earth, some metals are made by spraying powder out a nozzle and melting it with lasers. "In space, you can't really use the powder, because it would float all over the place," says Day of the National Research Council.

Researchers at NASA's Langley Research Center say they might have a way around the problem. They're working on a technology they call EBF3, for Electron Beam Freeform Fabrication. An electron beam gun melts two strands of wire into a 3D shape a layer at a time. No molds or tooling dies are necessary, and the process takes hours, not days or weeks, proponents say. "The thing we like about this application for space is that it's not a powder bed [printing] system that you obviously may have difficulty with in a vacuum," says David Dress, deputy director of Langley's Space Technology Program Office.

A big challenge was the size of the system. It once took up a small room but has been reduced to the size of a table top, making it "more appropriate for space," Dress says. The system has been shown to work aboard a zero-G aircraft, and will provide "the opportunity to show the value in creating parts that could be usable in an environment like the space station and eventually on the moon and Mars," Dress adds.

Keith Belvin, Langley's chief technologist, says the technique would be applied only when required. "It's not just that we

like metal 3D manufacturing. I'm actually a fan of the plastics and advanced materials systems also. But there are some parts where you need the strength of metals."

Contour Crafting

Print your house: The Contour Crafting machine developed at the University of Southern California releases quick-setting concrete to build structures layer by layer. The method could someday be used to build huge structures on the moon.

Rocket engines and satellite sensors

Many additive manufacturing advocates say great promise has been shown for Earth-based aerospace manufacturing. Last year, NASA Marshall generated a record 20,000 pounds of thrust when it tested a liquid oxygen and gaseous hydrogen injector made by laying down nickel chromium in a laser sintering process. The part, made by Directed MFG, Inc., of Austin, Texas, is similar in design to injectors for large engines, such as the RS-25 engine for the Space Launch System. "We're still going through the data on how the test progressed and what the results were, but all indications are that this is a good way of being able to reduce the cost of building engine components," says Keys, the Marshall chief technologist. "Ultimately I think additive manufacturing is going to be a substantial part of bringing engine costs down, increasing the quality of components and being able to more rapidly make them."

At NASA's Goddard Space Flight Center in Maryland, researchers are exploring 3D printing for highly customized spacecraft and instrument components, and for applications such as removing heat from spacecraft electronics, protecting circuitry from radiation, and building sensors, lighter structures and optics for space instruments. Additive manufacturing would have advantages for complex components, says Ted Swanson, the assistant chief for technology in Goddard's Mechanical Systems Division. An example might be a gamma ray sensor, which requires an insulator, conductor and very precise micro holes. "This is something you'd probably do with traditional manufacturing, but it would be very labor intensive and extremely expensive and take a lot of time too," he says. "In the additive manufacturing process, you could try something out quickly, then determine whether the basic idea works correctly or not and proceed to building the final article. That's one of the big benefits for additive manufacturing – a fast turnaround for one-of-a-kind projects. And we do a lot of that around here."

Building structures on the moon and Mars

One of the bolder in-space additive manufacturing concepts is the idea of robots fabricating large structures on the moon and Mars. Behrokh Khoshnevis, a professor of industrial and systems engineering at the University of Southern California, has received NASA Innovative Advanced Concepts funds to research this idea with the Swamp Works lab at NASA's Kennedy Space Center. Khoshnevis has developed a method he calls "Contour Crafting," in which layers of quick-setting concrete are laid down under computer control. Khoshnevis wants to use the technique on the moon or Mars to make structures including landing pads and walls to shield humans from radiation.

"The Contour Crafting machine would basically be a robotic arm sitting on some kind of rover," he says. "The rover does not have to be too big, because it can move around and also can raise itself. So therefore we can build pretty high structures and pretty large ones." He says lab tests have "demonstrated the validity" of the approach. For lunar applications, "we are proposing to

take the lunar soil and melt it, much like flowing lava in volcanic situations on Earth, and extruding it directly," he explains. Next, he wants to demonstrate the fabrication process with a stationary robot to build a structure that would be four or five meters thick.

Made in Space

Jason Dunn, left, and Mike Snyder of Made in Space work on the 3D printer, scheduled for launch on a SpaceX Dragon module in August.

NASA's spending on 3D printing research is receiving high-level, if qualified, support. "Additive is not going to be the be-all for everything. But it's right now undergoing a revolution where it's going to be useful for many things," says LaNetra Tate, principal investigator for the Game Changing Development Program within NASA's Space Technology Mission Directorate. "We want to invest in the technology that's going to help drive our missions and support our stakeholders. We also want to be on the cutting edge and help industry and academia accelerate technology where they can't do it by themselves, and NASA can play a supporting or leading role."

When it comes to in-space applications, there are still tough questions to be answered, for example about the power requirements for large-scale manufacturing in space and whether new materials can be mass produced with adequate quality controls. The good news, advocates say, is that the planning required for future human missions will provide plenty of time to conduct test bed studies within a long-term strategy of support to NASA's mission.