3-D Printing: We Ain't Seen Nothing Yet

Jack McGuinn, Senior Editor

A long time ago, in a galaxy far, far away—otherwise known as The '50s—3-D was shorthand for a new motion picture technology designed to get the public back in the movie theaters and away from their TVs.

ISS commander Butch Wilmore displays a working socket wrench — with ratchet action capability — that was printed using digital plans emailed to the station by NASA Mission Control (Photo courtesy of NASA).

Especially in the Westerns genre (extremely popular then), moviegoers were presented scene upon scene filled with spears, arrows, fists, chairs — or whatever was handy — seemingly flying off the screen and headed straight for them and their seatmates. But the public was underwhelmed by the new "technology" and 3-D-filmed movies were soon merely considered a quaint, less-than-awe-inspiring exercise in ho-hum.

Today, aside from a much improved 3-D technology that we can experience on our home flat screens and at the local IMAX, we now have 3-D *printing* — AKA additive manufacturing. But what's even more awesome — NASA is now 3-D-printing spare parts up at the ISS (International Space Station). And in *zero-gravity* environments. And some of these parts are small gears and actuators, *for starters*. Every indication is that the list of power transmission-type parts to be converted will soon grow.

"We have technically already printed a gear. The ratcheting wrench part, which is still the last thing we printed, contained a gear mechanism within its body," said Brad Kohlenberg, Made In Space business development engineer, adding, "We can also print mechanical actuators." Made In Space is a California start-up that has also partnered with NASA on a "recycler" project that will turn trash aboard the orbiting lab into 3-D-printed objects. That reportedly will happen by next year, if not sooner. Made In Space supplies 3-D printers and technical support.

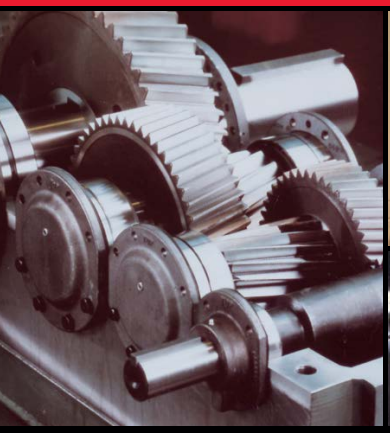
But unknowns remain. The parts printed in the zero-gravity space environment will be brought back for comparison testing — especially materials — with parts printed when the printer was earthbound. These findings should shed some further light on other potential gear, bearing, actuator, pump — who knows? — applications that are candidates for in-space environments.

What remains unknown, according to Made In Space, is the why behind the observed "minor differences" between made-in-space parts and parts printed on the same printer on Earth. To sort that out, "all of the parts printed as part of this initial technology demonstration will be brought back to Earth for tests conducted by the NASA Marshall Space Flight Center. These tests include the use of high-power microscopes and destructively flexing, pulling, twisting, and compressing some of the objects in controlled ways to determine standard material properties. The data that NASA generates from these tests will likely aid in the design of future materials and future commercial devices going to space."

OK — they're not printing complex bevel gear sets at the ISS yet. But does anyone doubt where this is going? Does anyone yet know how far this technology can take us? Or NASA?

Using the glass-half-full/half-empty analogy, Kohlenberg says that "If you mean half-full or half-empty in an optimism vs. pessimism way, we are just scratching the surface here. This technology will completely change how we plan space missions forever. The glass is very much half-full in that regard. If you mean how full is the glass in terms of progress, I think that depends on what your end-point is, or what your optimal 'full-glass' is filled with. Our goal is to create the technologies that will enable our species to become multi-planetary. To that end, off-world manufacturing is a crucial technology for us and we are still very much in the nascent stages of its development."

Indeed, it was just last year, as reported at *NASA.gov*, "A 3-D printer, designed and built by (Made In Space), created an extruder plate — a piece of itself — on Nov. 24, 2014 — an hour-long process. The milestone marks a key step toward a future in which voyaging spaceships print out their own spare parts on the go and colonists on other worlds make what







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The extruder plate — measuring approx. 3 inches long by 1.5 inches wide by 0.25 inches thick (7.6 by 3.8 by 0.6 centimeters) — displays the logos of both Made In Space and NASA. Said Made In Space CEO Aaron Kemmer, "This is the first object truly manufactured off of planet Earth. It's a huge milestone, not only for Made In Space and NASA, but for humanity as a whole." Choosing the plate, which holds in the printer's electronic board and wiring, for the first part has symbolic significance for Kemmer. "It represents the idea that if something goes wrong on the space station, or future space stations, the crew and NASA now have the ability to build a solution."

For the uninitiated, 3-D print technology enables the design and production of parts (gears, bearings, couplings), modules, etc., from a "blank page" by pancaking thin layers of extruded materials on top of each other — as specified by blueprints via computer display. Acknowledged advantages thus far for this nascent yet already somewhat ubiquitous technology include faster production, increased flexibility, i.e. — the ability to create components in shapes impossible to accomplish through standard methods — and, one of 3-D printing's most attractive capabilities for any cost-sensitive process — rapid prototyping of complex, expensive parts (tools, gears, etc.) — in *minutes*, not days or weeks.

But 3-D printers in space stations, spitting out replacement parts — *that* gets the mind racing. The technology is already being heralded by NASA as a means to further develop space exploration in that no longer will astronauts manning space installations need to wait (months) for, say, a new actuator or bearing replacement part before continuing their work.

Made In Space CEO Aaron Kemmer stares through the windows of the Microgravity Science Glovebox with the Zero-G 3D Printer enclosed (Photo: Made In Space).

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Made In Space's NASA-contracted, first 3D printer, was sent to the ISS on September 21st, 2014. The ivory objects on top are duplicates of what will soon be some of the first objects ever printed off-Earth. In the background is the Microgravity Science Glovebox that will contain the printer during the 3D Printing in Zero-Gravity Experimentation (Photo: NASA/Emmett Given).

Indeed, a recent study by the space agency found that about 30% of parts aboard the orbiting lab could be manufactured with a 3-D printer.

And manufactured, apparently, with little difficulty; training, for example, seems to be a value-added non-issue.

"The printer was designed to be calibrated and operated remotely and thus be as easy and efficient for the astronauts as possible," said Made In Space's Kohlenberg. "The complexity of parts is not a factor in training as 3-D printing drastically reduces the complexity of manufacturing parts which would otherwise be difficult or impossible to produce. Another way of saying this is that complexity is essentially free with 3-D printing."

For now, all 3-D printed parts have by necessity been designed by Made In Space engineers. But that will change soon — especially with the arrival of commercial-type 3-D printers, as mentioned here by Kohlenberg.

"Our in-house engineers have designed everything from the printer itself to the parts that the printer has printed. This is mostly due to the fact that we are still wrapping up the very first technology demonstration and are just now finding customers. As soon as we launch the commercially available printer later this year, we expect the lion share of the designs to primarily come from our customers while our engineers will provide design support as it relates to printing on our printers in the zero-gravity environment."

Said Jason Crusan, director of NASA's Advanced Exploration Systems Division, "Additive manufacturing with 3-D printers will allow space crews to be less reliant on supply missions from Earth and lead to sustainable, self-reliant exploration missions where resupply is difficult and costly." And the technology will become even more important for manned missions to deep-space destinations such as Mars, according to NASA officials.

What's more, 3-D parts printing will have a much-needed, salutary effect on NASA's deep-space budget. Doing more with less is definitely an advantage — whether on the ISS or factory floor.

"We really want to see these things (3-D printers) become the building blocks for the future of exploration," Made in Space lead engineer Mike Snyder told *Space.com*. "They really can lead into sustainability in space, and actually make these missions that cost a lot of money be reduced just because you don't have to launch as much mass."

Adds Kemmer, "It starts with tools and spare parts, things like that, and eventually leads to habitats, structures and really everything that you need to live off-world."

'Live off-world' — the man says it as if it were already a reality — perhaps a sign that for NASA as well as space age entrepreneurs like Elon Musk — populating Mars is no longer a question of if — but when.

Not wishing to be left behind, the European Space Agency (ESA) plans to launch its own 3-D printer to the International Space Station in the first half of this year. In fact the agency also recently teamed with industrial partners to investigate using 3-D printing technology to build a moon base using lunar materials.

"3-D printing offers a potential means of facilitating lunar settlement with reduced logistics from Earth," Scott Hovland, of ESA's human spaceflight team, said in a statement last year. "The new possibilities this work opens up can then be considered by international space agencies as part of the current development of a common exploration strategy."

The NASA site explains the 3-D printer's presence on the space station as being part of the 3-D Print Project — a collaboration between NASA and Made In Space. The unit sent up last September aboard SpaceX's unmanned Dragon cargo capsule was then on Nov. 17 installed in the orbiting lab's Microgravity Science Glovebox by Expedition 42 commander Barry Wilmore.

Taking things one step beyond, Made In Space plans to launch another printer to the space station, on a production rather than a demonstration mission. This printer will be used for the aforementioned "recycler" project.

The second phase of the project will focus on actual use of production/replacement parts printed on the ISS, according to 3-D print program manager Niki Werkheiser, of NASA's Marshall Space Flight Center in Huntsville, Alabama. As with her counterparts, Werkheiser is thrilled with developments thus far. After all, not everyone gets a chance to be in on the ground floor of a new technology that by all indications definitely has legs.

"I think we're making history by, for the first time ever, being able to make what we need, when we need it, in space," Werkheiser said on *NASA TV* when the printer was installed. "Even though it may sound a little like science fiction, we're actually able to email our hardware to space instead of launching it." (Sources: *NASA.GOV,* NASATV.GOV and *SPACE.COM.*)

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NASA Embraces 3-D Printing

The ability to "print" everything from human body parts to works of art to rocket engines is rapidly changing the world of manufacturing. NASA has been involved in additive manufacturing, or 3-D printing, since the 1990s when it was still an emerging technology. In the early days, it was often called rapid prototyping. Designers used printers to make plastic models to explore possibilities before they built a more costly part with metal. Printers were too small and could not make the quality parts needed for NASA flight hardware.

Now, making a part with additive manufacturing is not only more cost-effective, but also the printers can make larger parts of higher quality and with different materials — or even combinations of materials. NASA is exploring the use of many types of additive manufacturing that can benefit every phase of NASA missions — from launch to science payload development to robotic exploration to deep space missions. Across the agency, engineers and designers are trying out many types of 3-D printers that work with a variety of plastics and metals, including titanium, aluminum, Inconel and other nickel alloys widely used in aerospace manufacturing. Often a computer sends a design to a 3-D printer, and the machine makes the part in fewer pieces than would be required with traditional welding and assembly. Some additive manufacturing processes melt plastic or metal wire to form a part. For example, electron beams can be used to melt metal wire. Others use lasers to melt metal powders layer by layer until a part is formed.

To put this new type of manufacturing to the test, NASA is printing and testing rocket parts, telescope optics, and even parts of experiment equipment. When it makes sense, NASA plans to take advantage of 3-D printing in almost every type of mission from launch vehicles to robotic landers to parts needed in a space habitat. The International Space Station has become a test bed for this new technology to explore additive manufacturing in space — the first step toward in-situ resource utilization on orbit or at exploration destinations. Indeed, the technology could prove critical to space explorers on future long- and deep-space missions. (*NASA.GOV*)