
NASA
3D Printing in Space:
The Next Frontier
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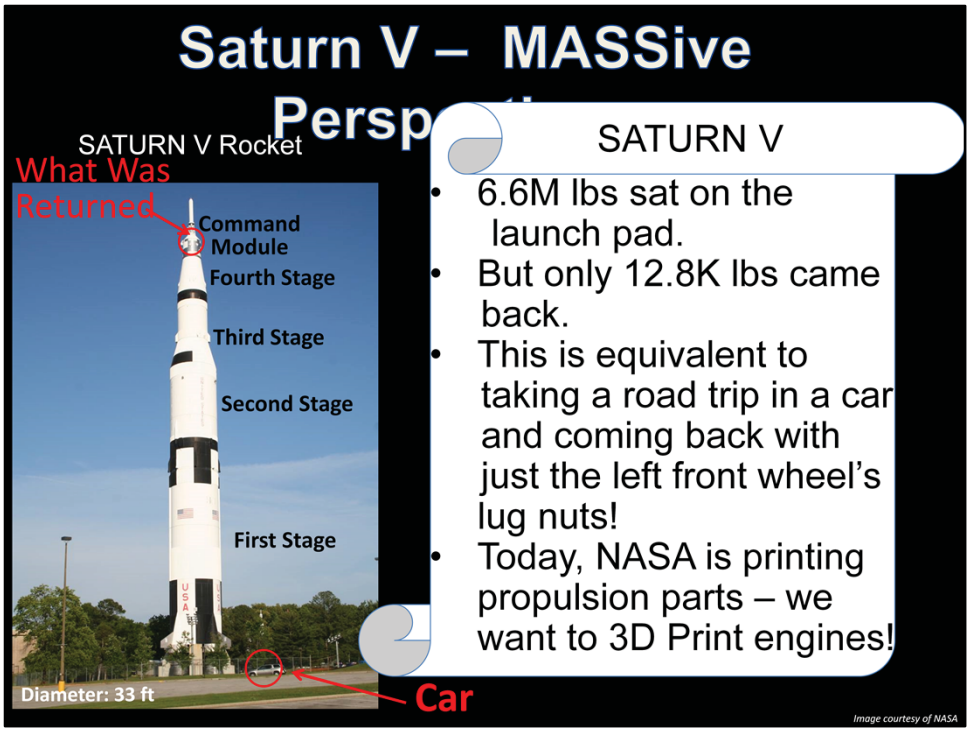
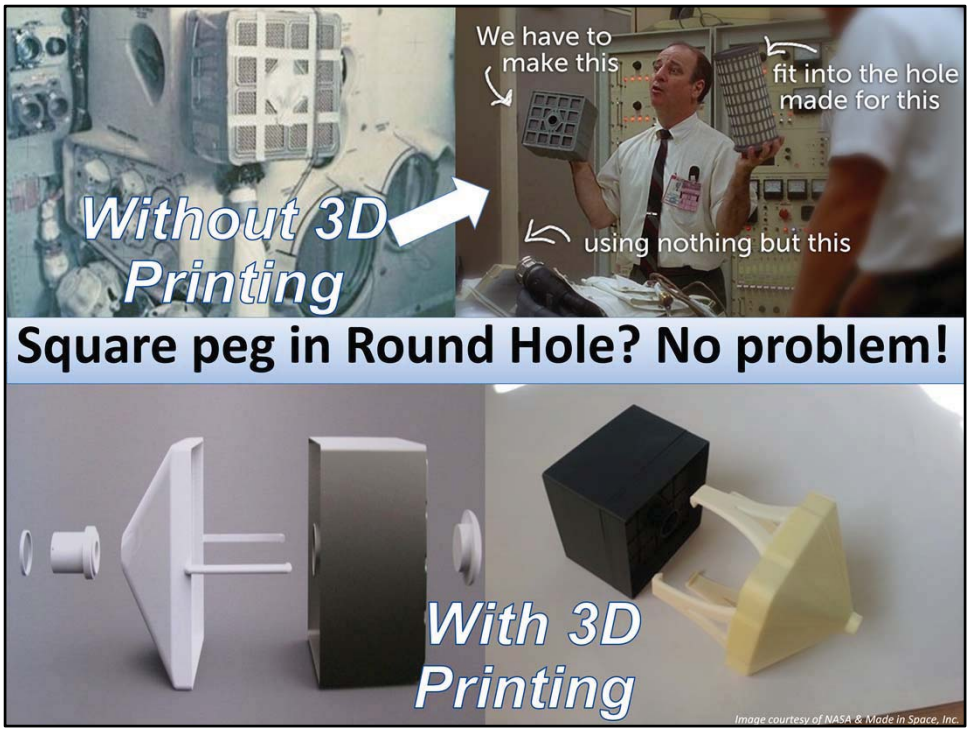
3D PRINTING IN ZERO-G EXPERIMENT
NASA MSFC • MADE IN SPACE, INC. • NASA ARC
Niki Werkheiser, NASA
3D Printing in Space Project Manager
Niki.Werkheiser@nasa.gov
256-544-8406

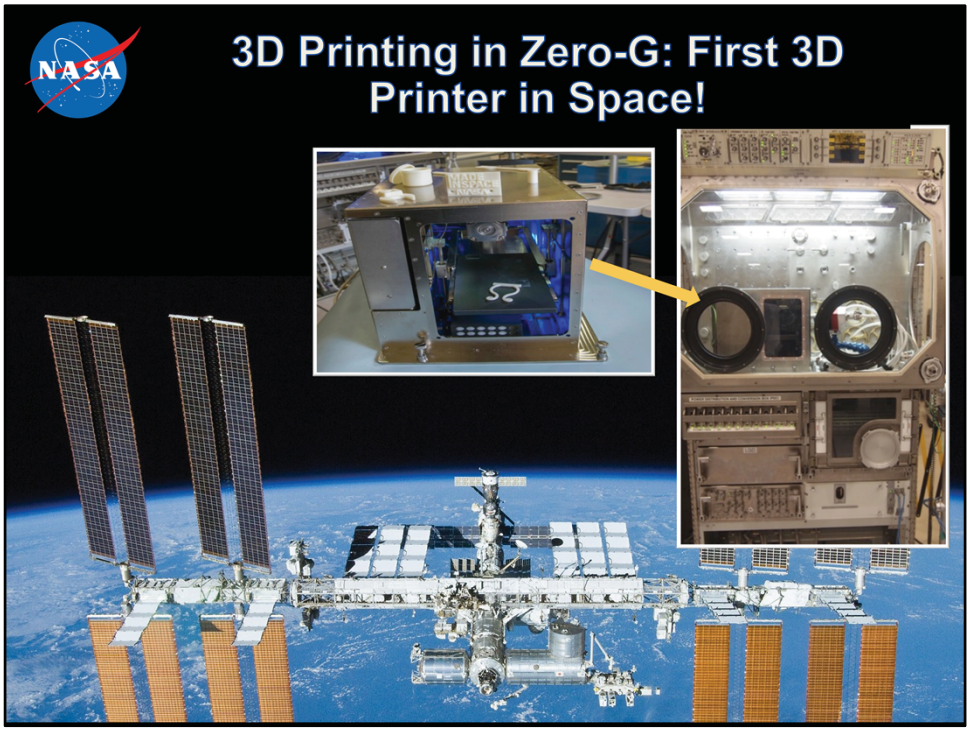
3D Printing is shaking things up all over the world – liberating users by decreasing the dependency on others for what they need by putting the manufacturing lifecycle in the individual's hand for the first time in history. But what effect could it have here? Space. Well, that's where the benefits go from novel or 'nice-to-have' to absolutely, beyond a doubt, game changing. That's because there are a few significant hurdles that we repeatedly face in the human space program, and they are particularly challenging when we talk about exploration missions to further out destinations like Mars or asteroids. *(Transition Mass/Risk/cost here)* These are mass, risk, and cost – and they are very much interconnected. From the inception of the human space program, we have had a very constrained (and that's putting it mildly) supply chain. Everything you might ever need must be launched from earth at a cost of $10K per pound - a cost, BTW, that we have never been able to reduce. Based on this model, mass, risk, and cost are further compounded by several factors. Firstly: if there are parts that are critical to the mission, spares must be flown just in case those parts are lost or broken, further adding to the mass. Secondly, the structural requirements to survive the launch-loads from escaping earth's gravity again – you guessed it – mean more mass for the parts launched. *(Transition here)* Lastly, and maybe most importantly, although NASA has done an amazing job making it work thus far, the current model is just absolutely not feasible for exploration missions. The cost, risk, and time required are just not realistic.



Since we're talking about mass and cost, I feel compelled to share this example of the Saturn V rocket, used during the Apollo program, with you because I think it really puts things in perspective. This rocket was a beast. Six million, six hundred thousand pounds sat on the launch pad to be launched. And 12, 800 lbs came back. So, to put that in other terms, this is equivalent to taking a road trip in a car and coming back with just the car's left front wheel's lug nuts! That's a whole lot of mass! Today, NASA is 3D Printing rocket propulsion components. Yes, you heard correctly. We want to 3d Print rocket engines!



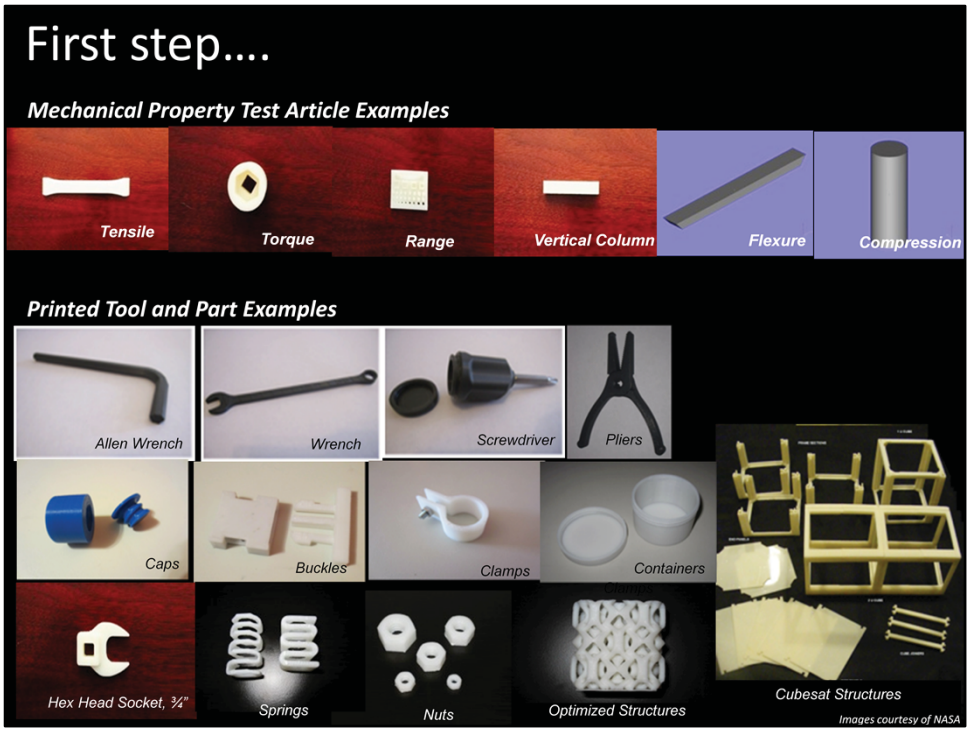
Now, we all know that space travel is inherently risky and there are multiple examples of challenging situations we've had on space missions from not having what we needed when we needed it. But one of the most well known (thanks in part to Tom Hanks) is Apollo 13. Many of you might be even familiar with the "square peg in a round hole' dilemma. In space, the carbon dioxide has to be 'scrubbed' out of the cabin atmosphere by filters or the astronaut's will die. But on Apollo 13, when the crew had to move to the temporary rescue ship, they found that the command ships filters were square but the rescue ship's filter barrel was round. Now, I'm sure many of you saw the movie and that means that you know that the heroic ground crew spent days developing an ingenious plan to use spare parts on board to make that "square peg fit into the round hole". But – let's consider for a moment what if the crew had had a 3D Printer? *(Transition to 3D Printed Part here)* Well, the company Made in Space, Inc. wondered that, too, so they came up with an exercise to test this. They brought in a high-school intern familiarizing the student that day of the issue and asking him to see if he could devise a 3D Printed fix. This high school student designed the fix and had the parts printed within hours. Now just think about that for a moment…a high school student was given the capability to devise and implement a solution that could prevent a previously life-threatening technical problem within hours of being presented it with it. Pretty cool, huh?



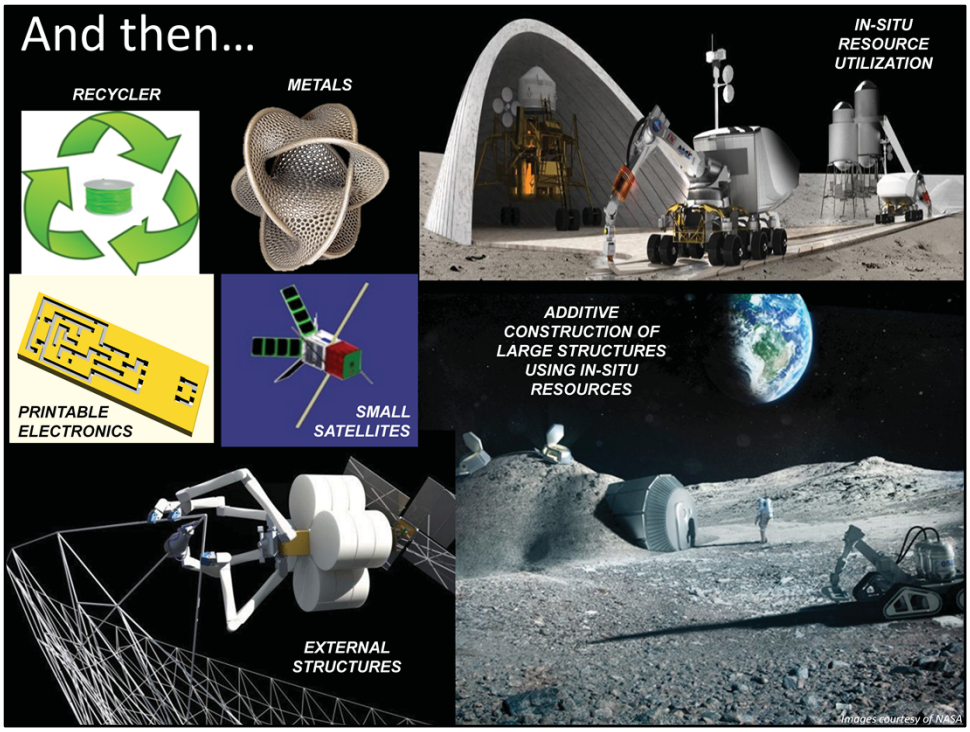
Well, we thought so, too, So that's why we'll be launching the first ever 3D Printer to the International Space Station on Space X 4 this fall.

The 3D Printing in Zero-G Technology Demonstration is a partnership between NASA and the company Made in Space, Inc. via the Small Business Innovation Research Program. As you might guess from the company's name, their entire business model is based around enabling human exploration. We at NASA, believe that being able to 3D Print in Space, is a fundamental and critical enabler to doing just that. Once the printer is on ISS, we will be able to uplink the CAD models for the parts we'd like from the ground directly to the printer. For that matter, we actually control most of the printers operations, including turning it on and off, monitoring the prints, etc. from the ground. The only function that the astronaut must perform is removing the part from the print tray once completed. So, when you think about it, we are actually taking the first step toward transitioning from launching our hardware to space to emailing it! I realize that may sound like Sci Fi – but it's actually Sci Fact.

And remember those pesky launch load requirements that drive up the mass of a part you're launching that I mentioned earlier? Well, if you can build the part in microgravity, you don't have to worry about launching it, so you don't have to worry about launch loads. This gets us very excited because it opens up the design space and options for what we print since we're actually building the parts in microgravity where will be using it!



The tech demo will have two phases. The first is simply to demonstrate that the printer and the process work in microgravity. NASA and Made in Space have flown 3D Printers on the aptly named "Vomit Comet' and all data has indicated that the print quality is equitable to that on earth. However, you only get 20-30 second durations of microgravity on those flights and even a small item, such as a clip, takes around 15 minutes to print, so the Space Station is literally the only platform in the UNIVERSE where we print entire parts in microgravity. We will also have high-definition cameras on the 3D printer windows so we can watch live from the ground as the parts are being printed. This will provide immediate feedback on the process, and we'll be particularly interested in seeing if the layers being deposited in micro-g are any different from process on earth. The very first printed parts will also be flown back to earth for detailed engineering analyses. Now, for the second phase of the tech demo we will turn the focus more toward the printed parts themselves and demonstrating the usefulness of those parts on space station. As you might imagine, these might include things such as standard hand tools, experiment hardware, exercise equipment replacement parts, medical tools, and even small satellite components. However, the aspect of the project I'm most excited about is that first call we receive from the astronauts requesting that thing that none of us thought about. That unknown, unknown, if you will, that we couldn't predict – and mark my words, it will happen.



Now, I'll be the first one to tell you that the 3D Printer is only the very first step toward establishing fully-sustainable technologies required to enable exploration. That's why NASA has an Exploration Roadmap and In-space Manufacturing will be required to bring that roadmap to fruition. 3D printing is a key technology, but for Exploration missions, we will ultimately need an integrated suite of capabilities. The current NASA In-space Manufacturing Initiative includes things such as being able to recycle the printed plastic parts back into raw feedstock material. That will be imperative to sustainable living and utilization. Recently, we awarded Phase I Small Business Innovation Research awards to two companies to develop a recycler for in-space use for a future payload on Space Station to follow the printer. The vision also includes such things as an in-space metals printing capability, printable electronics and printed nano satellites. But Ultimately, we will want to be able to use the in-situ resources from wherever we might be, whether it be the moon, Mars, or an asteroid, as our raw material to build radiation shielding and habitats, landing pads, and storage shelters, etc. The technology to print large structures such as these actually exists today – it's called Contour Crafting. At NASA, we are working with other entities interested in ground-based applications for this technology. For example, you might imagine that the Corps of Engineers, FEMA, and the Army might be interested in the potential for using local resources, such as sand or soil, to build structures during natural disasters, military deployment, etc.

And as much as I'd personally love to go to Mars, more than likely, it won't be someone from my generation to take that first step on the Red Planet. But, I do believe that it will be a student that's out there today. I have thought of nothing else than working for NASA since I was seven years old, so I feel passionately about sparking the excitement and fostering the skillsets required in the younger generation to equip them with what it's going to take to get us to Mars! What more exciting way to do that than for a student to design a part that gets printed on the International Space Station?

We are making that happen thru the Future Engineers Challenge that was announced at the White House Maker Faire in June and will kick-off later this month. The winning student will get to watch his or her part being printed live on ISS from the Payload Mission Control Center here in Huntsville at MSFC. I mean, can you imagine adding that to your resume before you even go to college!?

Unfortunately, I'm limited by time, but trust me, I could go on for quite some time about how many meaningful ways we can utilize these capabilities and what it's going to take to drive the technology to get us there. But the bottom line is that having the capability to make what you need, when you need it, wherever you are has larger implications than we can even imagine today. Much like the first printing press initiated a Renaissance by making info and knowledge available to the masses, I believe where we are with 3D Printing today is beginning to disrupt the traditional supply and demand model. We may just be taking that very first step today, but there is much more to come – on earth, and in space. I'll leave you with one parting thought that I believe most of you will be able to appreciate. The personal moment for me when I will know we have truly arrived is when we will just be able to just push a button and say…**. (Transition SLIDE).** "Tea. Earl Grey. Hot." Thank you all so much for your time!