Constellations Podcast

## Episode 5 – 3-D Printing in Space, Additive Manufacturing and Space Mining

Speaker: Andrew Rush, President & CEO, Made in Space – 20 minutes

John Gilroy: Thanks for listening to Constellations, the podcast from Kratos. Today's guest is Andrew Rush, CEO of Made In Space. Andrew, how are you today?

Andrew Rush: I'm doing well, thanks for having me.

John Gilroy: Well, I've done all my homework and I've learned all kinds of stuff about you, but tell me why in the world someone with your skill set wound up at a company like Made in Space?

Andrew Rush: Well, you know, I grew up on the east coast of Florida, watching launches and both my parents are engineers so I was on this steady diet of science fiction and hard physics, and really just always wanted to work in space and kind of circuitously got there. I have a technical background in physics and then I was a lawyer for a couple of years and was outside general counsel for Made in Space, and then after a few years of that was invited to come run the company, which was really just a dream, absolutely a dream job. I really enjoy every single day of it.

John Gilroy: I have to admit, I saw your LinkedIn profile. You have a bachelor's degree in physics, and then a law degree. It's kind of like, in the morning, you're a Red Sox fan and in the afternoon you're a Yankees fan. So you've got two different poles pulling you, don't you?

Andrew Rush: It's certainly a bridge between two worlds.

John Gilroy: Well, what I want to know is, how'd you get so much ink? Here it is. I see articles about you in Forbes, I get to see articles about you in Scientific American. I mean, these are pretty well-known publications and they write about some of the innovations that your company has. I mean, that's a great story to tell, isn't it?

Andrew Rush: Yeah, I mean, I feel really really fortunate to lead an incredibly brilliant team and we're accomplishing real things, making real progress in this emerging area of in-space manufacturing, whether it's building the first 3-D printers to operate in space, or successfully manufacturing extended structures in thermal vacuum chamber that simulates the environment of lower orbit, or miniaturizing a fiber draw tower, and then putting that on the space station to manufacture this really exotic optical fiber called ZBLAN there. So we've got a lot of stuff going on, especially for a small company, and we're fortunate that it gets a little bit of attention.

John Gilroy: Great, great, great. I'm going to give a quote from your Twitter feed, and then ask you the first question. Your Twitter feed says, "Dream on Earth, build among the stars." Get a lot of resumes with that, don't you?

Andrew Rush: Yeah, that really crystallizes what we're going after as a group, what our big goals are, that we view manufacturing in space as a fundamental shift in the way that humanity is interacting with its environment. We view manufacturing in space as that real driver to get people into space, living and working sustainably there. Which, like a lot of other companies in this industry, is a huge motivator for us in space.

John Gilroy: So I did my research this morning. I got up early and went to Google trends and typed in 3-D printers, and then I saw it started in 2004, and then had a big bump right in 2012. So tell us how 3-D printers interact with your company and when your company started, please.

Andrew Rush: Definitely. So Made in Space was founded in 2010, again, with this kind of explicit goal of enabling people to sustainably live and work in space. And the way the company approached that was to say, okay, what are some really transformative or emerging technologies that we could leverage to make it easier for people to live in space, and for it to be a profitable, both commercial and government, endeavor. And 3-D printing is a relatively old technology, but had started getting a lot of attention in kind of smaller niches in 2010. As we progressed, it's obviously gotten a lot more attention. It's kind of on the tip of everyone's tongue now, from an emerging interesting manufacturing technology.

So we've benefited a lot from new developments on terrestrial 3-D printing as well as people becoming more and more comfortable with terrestrial 3-D printing. When the company was first founded, you'd go into a customer and say, "Hey, we want to put a 3-D printer in space," and they'd be like, "Well, what's 3-D printing?" But now, because everybody is so more familiarized with it, and it's been the hot technology for a while. You go in and you say, "Hey, we want to do metal 3-D printing in space." Everybody's like, "Yes, that's awesome. We need to do that right now."

John Gilroy: I've been involved in technology for many years. I've never used the phrase 'terrestrial printing' before. I guess I'll walk down the hall and I'll print out ... I'll do some terrestrial printing today.

So I have a friend whose father is an astronaut, a guy named Fred Hays. And the time in space is very, very precious. I mean they try to do everything they possibly can. And I think one of the motivations behind Made in Space was taken ... and maybe an astronaut said, "I'd like to leverage that time I have in space, and do more while I'm up there." Is that one of the motivations behind this whole product?

Andrew Rush: Yes, absolutely. Really at the end of the day, having a local manufacturing capability is about augmenting the mission and saving astronauts time, and really, where possible, providing them that perfect fix, or that perfect tool, or that perfect new scientific instrument or structure, so that they can either do their mission better, or in the case of an event, they can recover from that very quickly and confidently.

There is a lot that goes into that, from material choice, to how we design the printer, to how it's operated. The printers we have on the International Space Station area are actually remotely operated. The astronauts aren't doing CAD and then loading up a file in it, or anything like that. We're sending the files to the machine, telling it to print, monitoring it, and then when it's done, the astronauts get a signal and then they can float over to the device and take the part out. And that's really all the interaction they have with it. Because their time is so precious, we want to provide them something useful with the minimal amount of time, while taking the minimal amount of their time.

John Gilroy: I went to YouTube and I saw an interview you did with someone called Moonandback guy and you talked about if you go down to Florida and you see one of these rockets sitting in there, I think 99% of it is just getting it in space, and just a very, very small payload. And so what 3-D printing allows is you overcome some of those limitation boundaries of a payload going into space, don't you?

Andrew Rush: Yes, absolutely. Something like 90 or 95% of the design requirements that are put on satellites and spacecraft today are driven by the launch vehicle, by the first sort of ten minutes of your assets operational life because that rockets adjusted their payload to really, really high g-forces, high shock, and high vibration environment, and you over-build your payload to survive that time and then you put it into space, it gets on orbit, and it's in this really kind of mechanically benign environment, just floating along in microgravity. So manufacturing in space lets us kind of dump all those requirements, or dump a vast majority of those requirements, because we can just launch feedstock, which doesn't really care about how many Gs it's subjected to, and a robust manufacturing device in space and then manufacture reflectors or boons or trusses or other structures that might normally be folded up and stuffed inside that launcher on that rocket.

John Gilroy: Yeah, it's kind of like origami, isn't it? They have to fold up these things real carefully and then it expands. This kind of overcomes some of those limitations.

Andrew Rush: Exactly, exactly. The ability ... it just opens up the design space so much. When you think about, what are our jobs as engineers and scientists? Our jobs are to optimize for the problem set that we have or find the solution and optimize the solution. So if we can manufacture in space, we can create structures that can only support themselves in zero gravity and really optimize for that operating environment rather than sort of origami folding something up to survive the delivery mechanism.

John Gilroy: I'm going to make up a silly story then turn the tables. So, I'm circling the Earth, and I need a 9/16 wrench. I forgot to pack one and so you can manufacture one pretty easily. However, we can turn the tables on this too. There could be advantages to manufacturing items in space and then take them back down to Earth. Is that right?

Andrew Rush: Yes, that's absolutely right. So, going back all the way to Apollo 14 or maybe even earlier, NASA, the Russian Space Agency, ESA and other groups have been doing materials research in space and studying the effects of the space environment and microgravity in particular on the behavior of materials in the process. And it turns out that there's a whole class of materials that we call space-enabled materials, that if you process them or manufacture them in space, they have really, really nice qualities. They have better qualities than if you did that processing or manufacturing on the Earth.

One of these in particular is an optical fiber called ZBLAN. It's an exotic optical fiber that has a transition window that goes deep into the infrared, and it actually has a signal loss that's like 10 to 100 times better than your sort-of traditional silica fiber, which is what is all over our telecommunications networks. There's about 20 years of research that shows if you manufacture this ZBLAN optical fiber in microgravity, you can actually attain that incredible performance gain because when you manufacture this material on Earth, little micro crystals form in it because gravity is kind of messing with the ability of the crystal lattice to set up. So if we take gravity out of that manufacturing equation, the lattice sets up well and we get really nice fiber.

John Gilroy: So I guess it would be applied in a data center or something? Or where would you apply that on Earth?

Andrew Rush: Yeah. The big long-term markets for it are actually long-haul telecommunications and data centers. And there's some other interesting applications in fiber lasers, super-continuum light sources, sensor applications, and more.

John Gilroy: We're here in Washington, D.C. area. The accounting area says 140 data centers. So it could be your next customer coming up, you know?

Andrew Rush: Yeah, definitely.

John Gilroy: There's always a cost to everything. So is it also less expensive? I know with higher quality out there for certain items, is it less expensive to manufacture in space?

Andrew Rush: On a per-kilogram basis, it's going to be more expensive because you have to pay for a really expensive ride up and back compared to what you would have to do on the ground. But the trick with something on ZBLAN is that on a sort of dollars per kilogram cost, is it really the right lens to be looking at something, looking at the problem. The appropriate lens is, what's my dollars per terabyte or dollars per unit of data that's transmitted. And in that frame, ZBLAN can be really, really competitive with traditional

silica fiber. It can provide a lot better response time, provide a lot more data per fiber, and give you a much wider transition window, all of which translate into great value for the customer.

John Gilroy: I'm going to bounce on, talk about country music now. There's a country music song and it was like, I was country before country was cool. So I got up this morning, went to LinkedIn. The first thing I saw was about the NASA webcam. So Andrew, I guess you used to be in an isolated field but now you're kind of in a really cool field where my first feed on linked in is about warming up to room temperature for this device that NASA's letting people all over the world watch. It is becoming very, very popular where it's been in the background for a while now and it's coming to the forefront of most people's minds.

Andrew Rush: Yeah, absolutely. It's really exciting to see and aerospace and the company and individuals that are doing good work in the industry, kind of attract a wider audience than it had even just a few years ago. I think it's really a testament to some of the really exciting and world-changing things that folks are doing in the industry, and hopefully we can kind of keep of that excitement and keep delivering on either industry as well as individual companies and people, keep delivering on the things we say we're going to do.

John Gilroy: I'd rather talk about country music but I've got to use a real serious phrase here that the engineers are really going to love. It's called 'extended structure additive manufacturing machine.' Boy, that's going to impress somebody, huh? So what do these fancy words mean, anyway?

Andrew Rush: So we call it ESAMM.

John Gilroy: Much better.

Andrew Rush: Yeah. So ESAMM is a technology that we've actually been developing for about six or seven years. It's an additive manufacturing device that's able to manufacture a structure that's much larger than the device itself. And this is a really key innovation because if you think about a 3-D printer, the image that probably pops into your head is a like box that chunks out things that are smaller than itself. So like a box that manufactures smaller boxes. And most 3-D printers that are that configuration are super useful but we probably aren't going to launch a 50 meter/side 3-D printer to space and then manufacture 20 meter reflectors.

What we really want to do is launch something that's like carry-on luggage size to space and have that create a 20 meter reflector. We want to launch something small that manufactures something larger than itself. And that's really what ESAMM is and what it does. Now it's able to manufacture things that are indefinitely long, in at least one axis. It's just limited by the amount of feedstock that you feed it. It's able to make really

complex structures because it's an additive manufacturing machine. And if you couple that with robotics to manipulate parts additive manufacture you can make a complex bolt structure using this technology.

John Gilroy: And so it is quite possible then, I'm just thinking out loud here is that, you could manufacture satellites from inside a satellite. It gives you all kinds of science fiction capabilities here, doesn't it?

Andrew Rush: Absolutely, absolutely. You can be really, really adaptive on the spot and manufacture repairs or reconfigure your satellite or manufacture little daughter satellites on that larger satellite. Really the possibilities are quite vast.

John Gilroy: What a tool and die maker would say is that, "Well what if a part on the printer breaks?" You could almost be self-repairing, you could almost print the part yourself and have it replaced. It's almost ... It brings a lot of different scenarios that people have only dreamed on in the past.

Andrew Rush: Yeah. Well it's funny that you mention that because actually one of the very first parts that was ever manufactured in space was a replacement cover for the extruder of the first printer that we built and operated. So really just, in a very tangible way, demonstrate what you just pointed out, that these devices can be self-repairing, and as the technology progresses, as we're able to get into ... As we have gotten not only into polymer manufacturing in space, but now have the ability to manufacture metal in space, and have demonstrated the ability to manufacture electrical connections, microgravity ... When you marry all that together, you very quickly start approaching a world where you're not only repairing, but you might one day have a self-replicating device that can manufacture an entire extruder and build a tray and traverse systems and all the systems and sub-systems that go into a space capable manufacturing device.

John Gilroy: Let me just back to a word you used earlier. The word was "feedstock". So what exactly does that mean?

Andrew Rush: So feedstock is the kind of raw material that additive manufacturing devices use to create the part that you specify. So depending on the 3-D printer, the feedstock comes in different forms. Sometimes it comes in like a filament or a spool of filament that is fed through an extruder and deposited in a kind of a raster pattern. Sometimes we actually use that technique for a wide variety of polymers. You can also use that for a wide variety of metals. We and our partners are pretty skilled at that. There are other techniques that are maybe not as well-suited for space, where you use a powder, like a fine metal powder as your feedstock and then you cincture it together with a laser and create your part. And the reason 3-D printers that use a liquid resin as the feedstock that then you cure with a light source and create your part, and that one we've actually demonstrated the ability to control that liquid in microgravity, which is really tricky. But that can yield some really, really high-resolution and interesting applications.

John Gilroy: You know my daughter is an engineer. When she studied engineering one of her classes, I think was materials and structures or something like that. It's like you're turning that class upside down. I'm sure all the teachers are getting mad at you because it's ... Andrew Rush is a new teacher on ... forget all that stuff you learned. This is way different types of materials and structures, isn't it?

Andrew Rush: Oh yeah. I mean the material size is probably one of the key three pillars with additive manufacturing and there are just so many brilliant people who are studying and developing these techniques and these materials. We have the pleasure of having good materials group in house at Made in Space. But certainly we leverage the incredible pace of innovation in material science that the broader industry has as often as we can.

John Gilroy: One topic that seems to be bouncing around here is the concept of mining in space. Does 3-D manufacturing have any application there?

Andrew Rush: Yeah. We like to say that, hey, we don't care where the feedstock comes from. We just need the feedstock. So if a mining company goes and processes an asteroid and has a couple of tons of nickel that they can deliver to us, then we'd be pleased as punch to turn that into a space station or part of a satellite or what have you. But really this additive manufacturing technology, and really space-capable manufacturing technologies in general are really fit hand-in-glove with mining of metals and other building materials in space because you really have to ask yourself, once you have the raw material, what are you going to do with it? And the answer is, well, we're going to build stuff in space. And that's where folks like us come in.

John Gilroy: I can see classes being filled up all across the country; just ‘tell me more. I want to learn more.’ I think of Bruce Willis and going to the asteroid and blow it up, he's actually in the mine. There's all kinds of really fun aspects of this, aren't there?

Andrew Rush: Yeah, definitely.

John Gilroy: You know, you sit around, talk with some young folks, you talk about mining in space, you talk about IoT as well, Internet of Things. Where do you fit in the whole topic of IoT?

Andrew Rush: So 3-D printing, additive manufacturing, is often used to prototype and over the next couple of years will likely be used to just straight up manufacture a wide variety of products. And many of those are going to be IoT products. So today we're using 3-D printing to kind of prototype those things and tomorrow we'll be using it to do direct manufacturing in both.

John Gilroy: We just have a couple minutes left here. I've got to ask you the forward thinking question. So, lets' say you can see into the future and ten years from now, twenty years from now, your kids, what are they going to be thinking about as far as manufacturing in space? Man, I can't imagine some of the topics we've even brought up today.

Andrew Rush: Yeah I really hope that in ten or 20 years my children will look up into space and say, "Well there's a little commercial space station that people are manufacturing high-value goods on and there's another and there's another." And they're looking up and saying, "Okay, what else could we do? What else could we eat?" Could we be using space to provide value. So hopefully they're looking at that and saying, "Yeah." Or pestering me to say, "Hey Dad, can we go on vacation in lower orbit?" Or saying, "I want to be one of the first moon explorers, prospecting for minerals." That's really the world that I hope exists in 20 years.

John Gilroy: That's going to be a brave new world, we know that. Well Andrew, it looks like we're running out of time here. For the last 26 minutes, we've been talking about cool space stuff. We're going to have to unfortunately end this interview here. I'd like to thank my guest, Andrew Rush, CEO of Made In Space. Thank you Andrew.

Andrew Rush: Thank you.