MADE IN SPACE

Testimony of

Andrew Rush

CEO

Made In Space, Inc.

Before the

U.S. Senate Subcommittee on Space, Science, and Competitiveness

Hearing on

“Reopening the American Frontier: Reducing Regulatory Barriers and Expanding American Free Enterprise in Space”

April 26, 2017

Russell Senate Office Building, Room 253

Washington, DC

MADE IN SPACE

Introduction

Made In Space, Inc. (Made In Space, MIS), seeks to develop products and services that will enable and drive people to one day sustainably live and work in space. In 2014, Made In Space hardware successfully produced the first functional objects manufactured off the face of the planet. Today, Made In Space has several in-space manufacturing programs underway and is commercially manufacturing for customers aboard the International Space Station. This success would not be possible without the Small Business Innovation Research Program, NASA support, and access to the International Space Station National Lab.

Via in-space manufacturing, Made In Space is developing the first factories in space which will produce high-value goods for use on Earth. These factories may one day be the anchor tenants of commercial space stations.

Made In Space strongly encourages continued support of programs which enable the step-by-step development of new commercial space capabilities, including the SBIR program, NASA's Flight Opportunities Program, and the International Space Station National Lab. Made In Space believes that personal and intellectual property created by commercial enterprises in space and aboard the International Space Station should be owned by the commercial entity. Further, Made In Space encourages the creation of a transition plan to commercial space stations before the International Space Station is decommissioned and expanded support for commercial activity aboard the International Space Station in order to effectively foster the birth of the cislunar economy as NASA's activities looks deeper into space.

The Cislunar Economy Is Coming

This is a unique time in history. Although the creation of a cislunar economy has long been discussed and dreamed of, sustainable, space-based, commercial manufacturing, tourism, and research and development has long been elusive. Today, sustained progress is being made toward this dream because the basic technological and regulatory framework exists to allow growth of space-based businesses.

We are on the cusp of the next great American technological boom: the creation of a sustainable cislunar economy. This boom is not guaranteed. Investments must continue in order to properly germinate this boom. This boom will encompass commercial satellites leveraging the best technology the American semiconductor industry has to offer, consistent space tourism activity sending people on suborbital, orbital, and translunar adventures, space-based research and development discovering new drug and compound formulations which can be made on Earth, and space-based manufacturing of products for use on Earth which provide revolutionary capability due to being manufactured in the microgravity environment of space.

Like every boom that has come before, from the smartphone revolution, to the Internet boom, reaching back to the booms like the one brought on by the discovery of oil at Oil

Creek, Pennsylvania the mid-19th century, many approaches will be tried, to varying success. In the creative destruction of progress, many will try. Some will fail. Some will succeed. Importantly, space entrepreneurs must be allowed to experiment, fail in small or grand ways, succeed in small or grand ways, and scale their businesses as the market demands.

Infrastructure enables and enhances economic booms. Without public and private investments in things like ARPANET and legislative actions to enable profit making via the Internet, the Internet boom would never have happened. Without investment, maintenance, and enhancement of the Global Positioning System, businesses and services like Yelp and Google Maps could not exist and our smartphones would be pale shadows of the powerful devices they are today. Going back further, without railway and eventually pipeline infrastructure created by public and private entities, transportation and refining of oil into kerosene and other products would have been severely constrained.

A boom in commerce in low Earth orbit and beyond will be no different. This space boom will be built upon infrastructure investments by both the private sector and the public sector. Some of this infrastructure exists already. The International Space Station (ISS), the International Space Station National Lab, and the regular human and cargo missions to and from that installation enable world beating scientific research and development, new understanding of the effects of space on the human body, and provide a platform for pathfinding the technologies and business models that may become the anchor tenants of future commercial space stations.

Crucially, the ISS allows deployment and operation of payloads to space at a fraction of the mass a free flying satellite would require to support the payload. Combined with the frequent cargo modules launched to the ISS, this creates an ecosystem which allows payloads to be flown to space and operated at a low price point and a frequency that is currently unattainable by the orbital launch industry. At a relatively low cost, this infrastructure allows commercial companies to develop technologies, test business models, and make profits that may one day support sustainable operations in commercial space stations or free flying satellites, where the full promise of sustainable commercial space industry will be realized and billions in revenues will be generated.

The ISS allows development, testing, and deployment of pilot commercial facilities for investments on the order of millions of dollars, amounts of money that can be realistically attained through private investment or public sources, such as the Small Business Innovation Research program. Without this infrastructure, such development and deployment would cost a hundred million dollars or more; an amount of money which is rarely invested in unproven space technologies by either the private or public sector.

Like the ISS and the ISS National Lab, other infrastructure supports the gradual, step-by-step transition of technologies which will enable a space-based economic boom from

the drawing board to full scale operation in space. The increasing availability of parabolic aircraft flights and suborbital rocket flights provides very low cost to no cost testing of technologies in short bursts of microgravity ranging from twenty seconds to several minutes. This enables low-cost prototypes to be tested in their intended operational environment, without the enormous expense of orbital launch. NASA's Flight Opportunities Program has long provided these flights to researchers and entrepreneurial companies, laying the groundwork for government and commercial payloads that have now been deployed to space.

On the operational end of the spectrum, we at Made In Space are ecstatic to see plans from commercial space station providers coming together to deploy modules to space within the next five years. Similarly, orbital launch providers bringing new, lower cost and reusable launch vehicles to market is a landmark achievement for commercial access to space. The combination of the ISS and future commercial space stations and frequent low-cost commercial launch gives companies at the forefront of the forthcoming commercial space boom somewhere to operate and a way to get there. Without somewhere to operate and a predictable way of getting there, operations are not possible and expansion of American free enterprise in space is stifled.

Made In Space, Inc. And The Emerging Cislunar Economy

Made In Space, Inc. (Made In Space, MIS) is a small business with offices in California, Florida, Alabama, and Ohio.

Made In Space was founded in 2010 with the goal of enabling people to sustainably live and work in space.

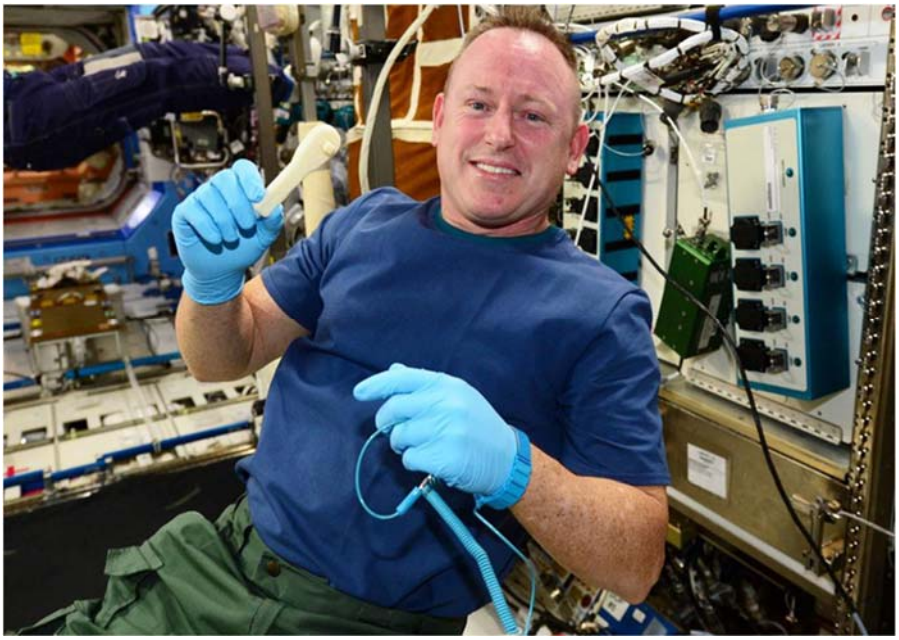

Figure 1. ISS Commander Barry "Butch" Wilmore holding a 3D printed ratchet manufactured in space. The ratchet was designed on the ground and manufactured in space one week later, making it potentially the fastest delivery to space ever. Image credit: NASA

This goal is shared by many in the space industry who believe in the economic promise the final frontier holds. Companies like SpaceX and Blue Origin are focused on building low cost launch vehicles, 21st century versions of the covered wagon. We at Made In Space are focused on developing the tools and manufacturing facilities that will fill those wagons to the stars, enabling a sustainable cislunar economy.

We focus on two types of space-based manufacturing: manufacturing technologies that enable new missions in space; and manufacturing technologies which leverage the space environment to create high value goods for use on Earth. Both are crucial enabling technologies for the cislunar economy which will utilize the above described infrastructure and one day generate revenues sufficient to profitably sustain commercial orbital launches and space stations.

Made In Space has no outside investors and has been profitable since its inception. Currently, Made In Space has approximately forty employees, including several who began their careers in the aerospace industry via internships funded by the NASA Space Grant and Fellowship Program.

Manufacturing In Space For Use In Space

Utilizing multiple pieces of the space infrastructure described above to open up new sources of space-based revenue, Made In Space engineers initially internally funded a prototype gravity-independent 3D printer. Through a grant from the NASA Flight Opportunities Program, that prototype was tested and successfully operated on board a parabolic flight aircraft in 2011. Building on this demonstration of viability, Made In Space was awarded SBIR contracts to develop the technology for demonstration

Figure 2. The Additive Manufacturing Facility (left) is the first ever commercial manufacturing facility deployed to space. A wide variety of customers have been served, including Lowe's who designed the first print on this facility, a space optimized hand tool (right). Image credits: NASA/Made In Space.

aboard the ISS. Via an SBIR Phase III contract with NASA run out of the In-Space Manufacturing group at NASA Marshall Space Flight Center, Made In Space built and operated the first 3D printer to operate in space. In late 2014, via the 3D Printing In Zero-G Technology Demonstration experiment, this space-capable 3D printer was installed on the ISS and manufactured the first functional objects ever made off the planet Earth by humanity (see Figure 1).

Building on this initial on-orbit success, Made In Space built the Additive Manufacturing Facility (AMF, see Figure 2), a second-generation more capable 3D printer. The AMF was launched to the ISS in March 2016. Via agreements with NASA and the Center for the Advancement of Science In Space (CASIS), the managers of the ISS National Lab,

Made In Space owns and operates the AMF, routinely sending print jobs to the ISS and manufacturing them on a weekly basis. The AMF print services business is profitable and has produced parts for NASA, the U.S. Navy, Lowe's, universities such as Texas A&M University, student groups, and even individuals. Parts manufactured include space optimized structures, hand tools for the ISS crew, prototype medical splints and ventilators, and adaptors for ISS equipment.

The capability to manufacture parts on demand during a space mission is paradigm shifting. 3D printing serves as a fast and inexpensive way to manufacture parts on-site and on-demand, reducing the need for costly spares on the ISS and other spacecraft. Long-term missions would benefit greatly from having onboard manufacturing capabilities. New parts may be manufactured to enable new scientific experiments or augment existing ones.

Figure 3. This artist's rendering depicts the Archinaut payload during its deployment in space. Via additive manufacturing and assembly, a large reflector is manufactured and integrated over time. Image credit: Made In Space

Further building on this success and internal research and development into manufacturing very large, space-optimized structures in space, Made In Space became a "Tipping Point" selectee by NASA's Space Technology Mission Directorate. Under a contract begun in late 2016, Made In Space is leading a team including Northrop Grumman and Oceaneering Space Systems to develop its Archinaut in-space manufacturing and assembly technology. During rocket launch, spacecraft are subjected to high g forces and large vibrational forces. Further, the entire spacecraft must fit within the limited volume of the launch fairing. Surviving this launch environment requires wasting mass to over engineer components to survive launch and engineering deployables which unfurl once the satellite reaches orbit, creating points of failure. Archinaut technology will enable optimization of spacecraft structures for their operational environment, rather than launch. Additionally, repair and reconfiguration of assets once they are on orbit will be possible. Further, this technology enables providing large structures at lower cost and enabling robotic manufacture and assembly of large reflectors, space stations, and other applications for civil, defense, and commercial space customers. Before operating in space, this technology will initially be demonstrated in NASA environmental testing facilities and aboard ISS via AMF, including manufacturing space-optimized structures in space.

The Archinaut Development Program is a private-public partnership designed to develop a technological capability that is useful to both government and commercial customers. As part of its effort, the Made In Space-led team is contributing over 25% of the program cost. Made In Space believes that space technologies should be developed into products which are useful and sold to both government and commercial space customers. This expands their utilization and lowers costs for all customers.

Manufacturing Space Enabled Products

Space-enabled products are materials and products which are manufactured and/or processed in space which, due to being manufactured and/or processed in space, have beneficial properties. Because of space's unique properties like microgravity, in-space manufacturing enables the creation of new materials and products which cannot be duplicated via Earth-based manufacturing.

Figure 4. Made In Space will deploy a payload to ISS this year to manufacture high value optical fiber in space. Image credit: Made In Space

Some products have been well researched via government funding and determined to provide significant performance improvements when manufactured in space. For example, research indicates that space-manufactured ZBLAN optical fiber has ten to one hundred times better signal loss compared to traditional silica optical fiber. Due to this dramatic performance improvement, some government and private analyses estimate that space-produced ZBLAN optical fiber could generate over a billion dollars a year in revenue. Commercial manufacturing of ZBLAN in space would also represent the first industrial use of space, a key enabler of the cislunar economy.

Because of its unique expertise in microgravity manufacturing and the market potential of ZBLAN, Made In Space has privately funded the development and deployment of a ZBLAN manufacturing facility. Via an agreement with CASIS, this facility will be flown to the ISS this year, produce optical fiber there, and then be returned to Earth where the fiber will be characterized and delivered to customers. Made In Space plans to scale in-space production of ZBLAN quickly aboard the ISS with the ultimate goal to produce thousands of kilometers of ZBLAN optical fiber a year in space on a commercially provided platform.

Made In Space is taking a step-by-step approach with this program, leveraging government research, the ISS, and its own profits to deliver a commercial in-space manufacturing capability. The promise of in-space manufacturing is not limited to optical glasses. Government and private research indicates that many other products and materials can benefit from in-space manufacturing and close the business case at

current launch costs or launch costs achievable in the medium term, making manufacturing of space-enabled products a potential anchor tenant of future commercial space stations in the cislunar economy and adding new launches to the industry.

Conclusion

Made In Space has benefited enormously from a virtuous cycle of technology development and operation enabled by the Small Business Administration, NASA, and CASIS. Made In Space is grateful to all those that have helped along the way and proud to continue working with NASA and other government agencies. The step-by-step technology development path that currently flows from lab development to parabolic flights through the ISS National Lab and eventually to commercial platforms in space has been critical to Made In Space's success. Made In Space strongly encourages continued support of the elements of this path as well as support and expansion of commercial enterprise aboard the ISS so that the cislunar economy is well positioned to blossom before the ISS is decommissioned. By actively supporting the growing commercial cislunar economy through the end of the ISS's life and supporting the creation of commercial platforms in LEO, the United States can expand its supremacy in space.