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Testimony of

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Before the

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Introduction

Fifty years ago, American innovation put American boots on the Moon for the first time. American innovation in space, driven by emerging companies like Made In Space, is alive and kicking today. We and our fellow innovators are ready to progress beyond Apollo, not only putting humans back on the Moon to stay, but revolutionizing the way spacecraft are built and creating sustainable, commercial business operations in Low Earth Orbit. Made In Space, Inc. (Made In Space, MIS) is developing technologies and business models 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 support of NASA via the Small Business Innovation Research Program, public-private partnerships like the In-Space Robotic Manufacturing and Assembly Tipping Point program (IRMA), and access to the International Space Station (ISS).

Made In Space-designed ISS payloads are proving out the potential of producing high-value goods in microgravity for ultimate use on Earth which will one day lead to factories in space. These factories may one day be the anchor tenants of commercial space stations.

Made In Space's activities on the International Space Station (ISS) and in ground test facilities have proven the potential of manufacturing and assembling satellites not on the ground but on orbit. NASA's Space Technology Mission Directorate recently awarded a Made In Space-led team a contract to build and launch Archinaut One, the first satellite that will manufacture and assemble portions of itself on orbit. This mission will definitively demonstrate the transformational potential of in-space manufacturing and assembly of satellites, enabling spacecraft to be designed and optimized for their operational environments, rather than hardened to survive launch. In the near term, via large solar arrays constructed on orbit for the satellite, this will provide a 5x improvement in power for small satellites. In the longer term, in-space manufacturing and assembly could enable large space telescopes and future space stations to be cost effectively constructed in space.

Due to the tremendous support of NASA and others, Made In Space will grow from forty employees at the beginning of 2019 to approximately 90 employees by the end of the year. Much of this growth will occur in the great state of Florida, fueled in part by support from Space Florida.

Made In Space strongly encourages continued and expanded support of programs which enable the step-by-step development of new commercial space capabilities, including the SBIR program, NASA's Space Technology Mission Directorate, and the International

Space Station National Lab. American space technology development generally, and small business innovation in particular, will be integral to Americans returning to the Moon to stay and going forward to Mars in the near future.

Technological innovation, especially small business driven innovation, is the engine which will keep us ahead of China and other nations. Space is acknowledged as integral to our national economy. It is also increasingly becoming a warfighting domain.. For these reasons, the US must redouble its efforts to develop new technologies and business models that utilize space for commerce, science, and defense.

In order to maintain and grow America's space-based edge over China and others, Made In Space strongly encourages continued support of programs that enable the step-by-step development of new commercial space capabilities, including the SBIR program, NASA's IRMA program, DARPA's support of in-space manufacturing and assembly development, and the commercial use of the International Space Station.

<u>Made In Space, Inc. and the Emerging Cislunar Economy</u>

Made In Space 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.

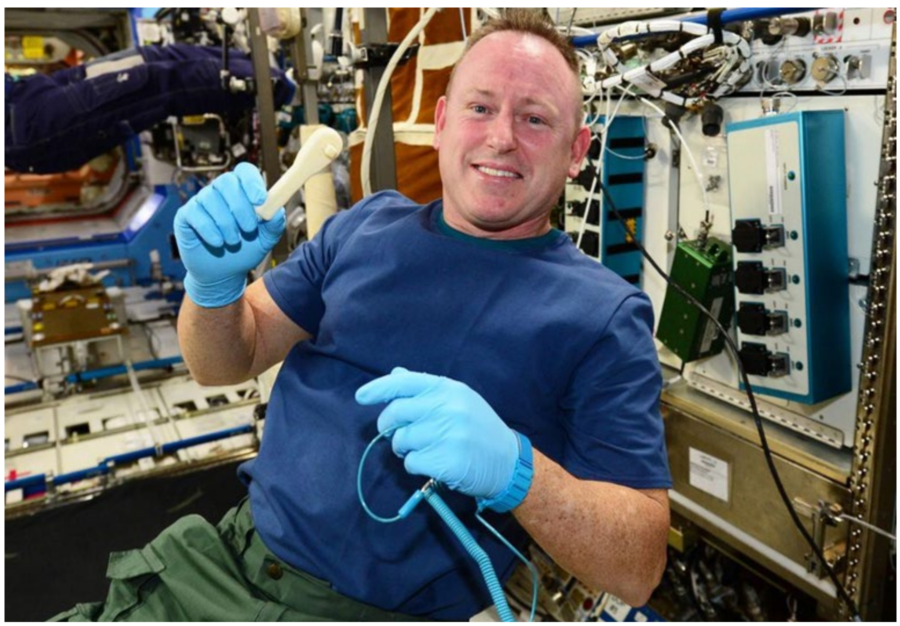

Figure 1. ISS Commander Barry "Butch" Wilmore holding a 3D printed ratchet manufactured in space. The ratchet was designed on the ground and manufactured in space one week later, making it potentially the fastest delivery to space ever. Image credit: NASA

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.

We focus on two types of space-based manufacturing: manufacturing technologies that enable new missions in space; and manufacturing technologies that leverage the space environment to create high value goods for use on Earth. We believe these areas will drive significant growth of American industry over the next decade. Furthermore, these areas will enable the American human spaceflight program to build on the success of Apollo and return to the Moon and go on to Mars.

NASA and Other Government Agency Support Enables Manufacturing In Space For Use In Space and the Future of American Industry and Exploration In Space

In-space manufacturing and assembly dramatically reduces spacecraft cost, reduces the limitations rocket launch places on spacecraft design, and removes astronauts from harm's way. Traditionally, satellite design has been constrained by launch-shroud size and launch load/environment survivability requirements. Similarly, due to lift capacity limits and the high risk and low availability of astronaut EVA for assembly, creating large space-based structures such as space stations has been a once-in-a-generation endeavor. Archinaut, our in-space manufacturing and assembly technology for self-assembly of satellites on orbit, minimizes or removes these and other design limitations.

In-space manufacturing and assembly enables a wide variety of desirable missions. These include large-scale telescopes for astrophysics missions, increased power production for small satellites, and future space station backbones. In-space manufacturing and assembly is also transformational for Lunar and Mars applications. Archinaut enables small form factor satellites to provide high resolution mapping and high throughput communications services necessary for sustained human and robotic operations on the Lunar surface. Previously providing these services has been accomplished by large and significantly more expensive assets. Additionally, these technologies enable satellites to be modified, repaired, or reconfigured on orbit, thereby enabling these assets to be more resilient and durable in a manner that does not exist in the current approach to satellite design, manufacture, and deployment.

Working closely with NASA, DARPA, and others and utilizing multiple pieces of the space infrastructure described above, Made In Space has made significant progress in developing and demonstrating in-space manufacturing technologies for both satellite applications and human spaceflight missions. MIS engineers initially internally developed 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.

Based on this success, Made In Space was awarded SBIR contracts to develop the technology for demonstration 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 (see Figure 1).

Thereafter, 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. Made In Space owns and operates the AMF, routinely sending print jobs to the ISS

Figure 2. The Additive Manufacturing Facility (left) is the first ever commercial manufacturing facility deployed to space. The first commercially manufactured part in space was a space optimized hand tool (right). Image credits: NASA/Made In Space.

and manufacturing them on orbit. 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. This commercial service is one of several pioneering commercial uses of low Earth orbit. These uses represent pathfinders for future commercial space station-based businesses, a future cornerstone of American industry's utilization of space.

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. One can imagine that the Apollo 13 mission would have faced less adversity if an on board 3D printer had been present. Rather than jury rigging together a wide variety of items to create an adapter for CO2 filters, for example, an on board 3D printer could have quickly and efficiently created the needed fix. Borrowing from fiction, when Mark Watney, the main character of Andy Weir's *The Martian,* was stranded on Mars, he could have been aided in surviving his trials and tribulations had he had access to local manufacturing equipment.

Further building on this success and internal research and development into manufacturing very large, space-optimized structures in space, Made In Space was selected to participate in the two-phase NASA Space Technology Mission Directorate In-Space Robotic Manufacturing and Assembly (IRMA) Tipping Point program . The IRMA program seeks "to transform the way we manufacture, assemble and repair large structures in space, leading us closer to a robust space infrastructure freed from launch window scheduling, launch vehicle mass limitations and astronaut safety concerns. Ultimately, [IRMA] will enable more frequent science and discovery missions in Earth orbit, across the solar system and beyond."[1] Furthermore, IRMA operates via "public-private partnerships to deliver technologies and capabilities needed for future NASA, other government agency, and commercial missions."[2] Tipping point technologies were sought. That is, technologies and capabilities which, if investment was made in a flight demonstration, there would be "significant advancement of the technology's maturation, a high likelihood for utilization of the technology in a commercially fielded space application, and a significant improvement in the offerors' ability to successfully bring the space technology to market" thereby enabling the capability to be available to NASA and OGA's but sustained by the commercial market, resulting in more cost effective and better technological outcomes for the government.[3]

Phase I of the IRMA program focused on ground demonstrations of in-space manufacturing and assembly technologies, maturing these technologies for flight demonstrations in Phase II where properly planned definitive demonstrations in space will push these technologies past the tipping point and raise their technology readiness level to the point that civil, defense, and commercial customers will utilize the technologies for operational missions. This programmatic structure and focus is enabling American industry to develop and implement technologies which will improve satellite design, operation in the future, providing significant advantages over the U.S.'s competitors.

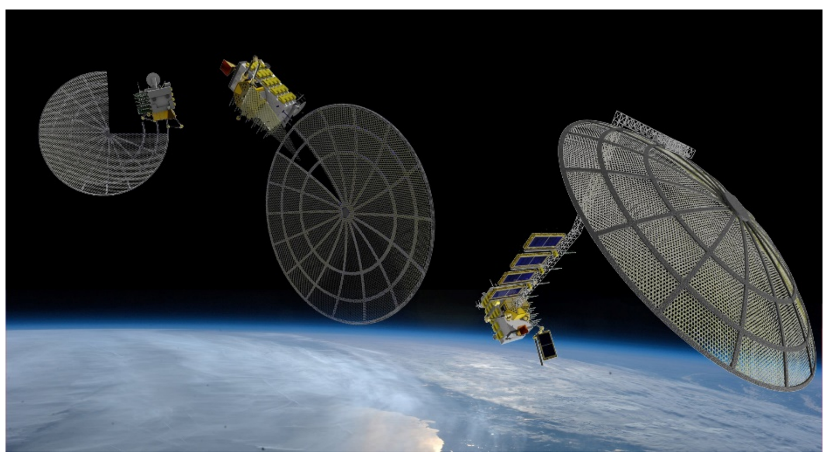

Figure 3. This artist's rendering depicts the Archinaut payload during its deployment in space. Via additive manufacturing and assembly, a large reflector is manufactured and integrated over time. Image credit: Made In Space

Under a Phase I contract begun in late 2016, Made In Space led a team including Northrop Grumman to develop its Archinaut in-space manufacturing and assembly technology (see Figure 3). During rocket launch, spacecraft are subjected to high g forces and large vibrational forces, which requires wasting mass to over-engineer components to survive launch. Further, the entire spacecraft must fit within the limited volume of the launch fairing, which requires engineering deployables that unfurl once the satellite reaches orbit, creating points of failure. Archinaut technology will enable optimization of spacecraft

[1] See: https://www.nasa.gov/mission_pages/tdm/irma/index.html
[2] See NASA Solicitation UTILIZING PUBLIC - PRIVATE PARTNERSHIPS TO ADVANCE TIPPING POINT TECHNOLOGIES appendix number NNH15ZOA001N-15STMD-001 to NASA Research Announcement (NRA): Space Technology - Research, Development, Demonstration, and Infusion – 2015 (SpaceTech–REDDI–2015), NNH15ZOA001N released May 21, 2015.
[3] *Id.*

structures for their operational environment, rather than launch. Additionally, Archinaut will enable repair and reconfiguration of assets once they are on orbit. Further, Archinaut will be able to build large structures at lower cost, including 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 was 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.

On July 12, 2019, MIS was awarded a flight mission to definitively demonstrate Archinaut. Made In Space will construct two ten meter solar arrays, on orbit, to power an ESPA-class satellite. Once on orbit, Archinaut One will employ its extended structure additive manufacturing capabilities and advanced robotics to manufacture and assemble the satellite's power system. The Archinaut-created solar arrays will yield nearly 5x the power currently available to ESPA-class satellites. NASA is providing $73.7 million in funding for this mission, with the MIS led team contributing an additional 25%.

<u>Manufacturing Space Enabled Products</u>

Space-enabled products are materials and products that are manufactured or processed in space and which, as a result, have beneficial properties. Because of space's unique properties like microgravity, in-space manufacturing enables the creation of new materials and products that 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 has flown to the ISS four times, produced optical fiber there, and then was returned to Earth where the fiber has been analyzed. Based on the initial promising results, 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 the company's own funds 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

As described previously, as many other small companies have, MIS has contributed in impactful ways to America's space program and looks to have greater impact in the future. The SBIR program enabled transformational ideas like 3D printing in space to go from the drawing board to demonstration in space. The vision of NASA's Space Technology Mission Directorate to invest in disruptive technology like in-space robotic manufacturing and assembly will enable satellites to demonstrate self-assembly abilities. In the future, this technology will transform how we build spacecraft, opening the aperture for human and robotic exploration of the cosmos and enabling commercial space operations to get more capability per kilo sent to space. Made In Space and its customers have benefited enormously from the virtuous cycles of technology development enabled by SBIR, STMD, DARPA, and others. Made In Space strongly encourages NASA to look to small businesses to serve integral roles in taking the United States back to the Moon and on to Mars via their technological innovations. Hand in hand with that, Made In Space encourages increased investment in space technology development. In particular, increasing support throughout the technology development pipeline mission-enabling technologies will minimize the risk that, at early stages of development, will languish. These investments are crucial to achieving America's near term ambitions in space and avoiding being overtaken, militarily or peacefully, by China or others in space. The subcommittee is uniquely positioned to extend the legacy of Apollo and help propel the nation back to the Moon and on to Mars by unleashing the time-tested power of American small business innovation.