A Bridge to the Future

SpaceTech White Paper

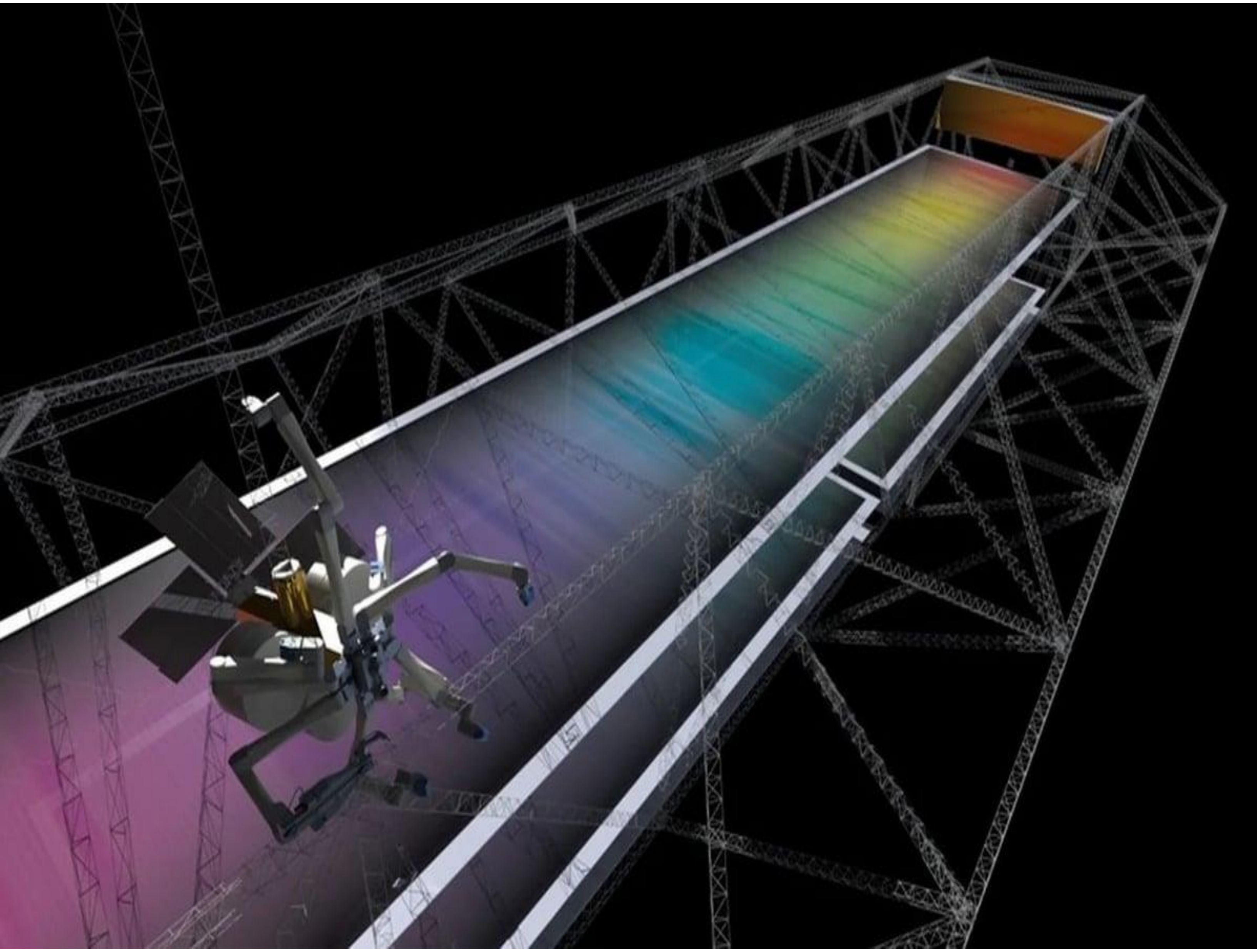


Image Source: AII3-DP

3-D Printing the Future of Humans in Space

Contents

INTRODUCTION

Human beings live at the bottom of a "gravity well." The Earth's gravity, or "1-G," keeps us tethered to the planet of our birth, and we must pay an enormous price in energy and money to reach Low Earth Orbit, where we are liberated from gravity and "Zero-G" takes over.

The gravity well makes it difficult for us to leave Planet Earth, or transport anything off of our home world. For many years, this has made living off of the planet in small numbers a topic for science fiction and has been a major barrier to Large Scale Space Migration.

Although the advent of reusable rockets has lowered the cost of reaching LEO, the cost of transporting materials remains high. One solution is In-Situ Resource Utilization, or ISRU. This means harvesting resources that are available off of the Earth to create what human beings need when they get to their destination. For example, a recent experiment on Mars tested the possibility of extracting oxygen from the planet's atmosphere. While this will, of course, be useful for humans to be able to breathe, the experiment was also aimed at using oxygen for rocket fuel. Imagine the savings if spacecraft could use ISRU to travel back to the Earth, rather than hauling all the fuel for the return trip to Mars on the outbound journey!

This is also why space agencies are so interested in searching for water on the Moon and Mars. If it is not there, resupply vessels will constantly be ferrying water (which is very heavy) from the Earth to these other celestial bodies, at a steep price.

It is also for this reason that some observers advocate mining asteroidal material to build free-floating space communities, avoiding having people live on planetary surfaces of any kind (more gravity wells). The one approach that must be avoided, if we are to flourish within the rest of the solar ecosystem, is to constantly bring materials and supplies from the surface of the Earth to LEO and beyond.

The International Space Station (ISS) represents a marvelous tribute to the creativity of human beings, and to the ability of nations on Earth to collaborate for a common good. However, it is not a scalable model for long-term extraterrestrial construction. For the most part, the components of the ISS were built on Earth and transported to LEO at a very high cost. Moreover, the supplies needed to keep astronauts and cosmonauts alive, and the tools that allow them to do meaningful work, typically need to be transported from the Earth to the station. In addition to the high cost of transportation, there is an environmental cost of frequent rocket launches.

For all of these reasons, being able to create what is needed off-world is a valuable capability, and that is where 3-D printing (also known as additive manufacturing) can make a huge difference. In addition to every application discussed thus far, we are seeing companies like Relativity Space creating spacecraft largely with 3-D printing. Once again, there are tremendous cost savings associated with this approach.

3-D printing is already revolutionizing space exploration and development, offering unparalleled opportunities to overcome logistical and cost challenges associated with off-Earth operations. This technology is being leveraged to create tools, components, and habitats in outer space, significantly reducing the need to launch all materials from Earth, thereby minimizing launch mass and costs.

3-D PRINTING TECHNOLOGIES—OVERVIEW AND LATEST DEVELOPMENTS

Two main 3-D printing technologies are currently being used in space. These are Fused Filament Fabrication and Electron Beam Melting.

Fused Filament Fabrication (FFF): This is the most common type of 3-D printing on Earth, and it is also finding good use in space due to several advantages:

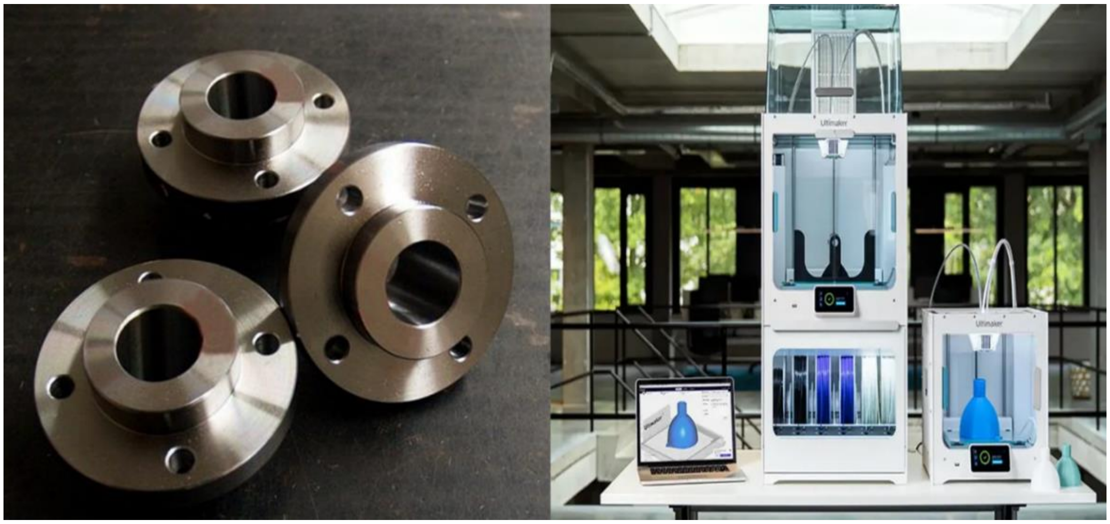
- Microgravity Compatibility: Unlike some other methods, FFF doesn't rely on gravity to function. It works by depositing thin layers of molten plastic filament which solidify quickly, building the object layer by layer.
- Safe for Crewed Environments: FFF uses plastic materials that are generally safe for astronauts to handle and that don't generate harmful fumes.
- Size and Power Constraints: FFF printers are relatively compact and have lower power requirements compared to some metal printing methods, making them suitable for space missions.

Electron Beam Melting (EBM): This is a metal 3-D printing technique that is being explored for space applications. It offers advantages like:

- Stronger Materials: EBM can print with metals like titanium and Inconel, which are much stronger than plastics used in FFF. This opens the door for printing structural components and even rocket engine parts.
- High Precision: EBM creates highly precise and complex metal structures.

Additionally, scientists are exploring other methods like bioprinting for creating tissues and organs, and even using recycled plastic waste on the spacecraft itself through machines like the Refabricator (the first recycling printer sent to the ISS). As these technologies mature, 3-D printing promises to revolutionize how we design, build, and live in outer space.

Chart 1: FFF and EBM 3-D Printing Technologies

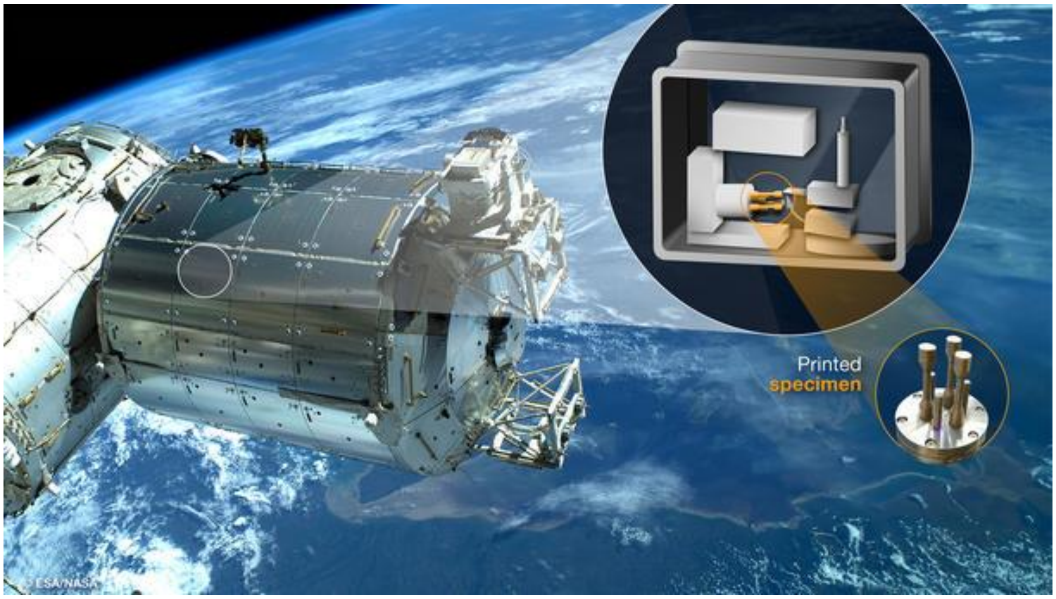


Source: Intro Act, Wevolver, AMFG

Metal 3-D Printing: Metal 3-D printing offers significant benefits for astronauts. While plastic 3-D printers have been on the International Space Station since 2014, they are limited in their capabilities to replacing or repairing plastic parts. However, not all components can be made from plastic, presenting a logistical challenge for supplying equipment to space stations, and future communities on the Moon and Mars. As the demand for parts intensifies in the future, metal 3-D printing emerges as a solution. Although the raw material still needs to be launched, printing parts in outer space proves more efficient than transporting them fully assembled. This advancement ensures astronauts will have the necessary tools and equipment for extended missions, reducing reliance on Earth for resupply.

At the end of January 2024, the world's first metal 3-D printer for space, developed by Airbus for the European Space Agency, was on its way to the ISS via a Cygnus cargo spacecraft mission. This printer is expected to bring new on-orbit manufacturing capabilities, including the possibility to produce load-bearing structural parts that are more resilient than a plastic equivalent.

Chart 2: The World's First Metal 3-D Printer for Space



Source: Intro Act, Airbus

In-Space Manufacturing (ISM): Both NASA and the European Space Agency are pushing ahead with plans for 3-D printing on the Moon and the International Space Station. The aim is to build housing, infrastructure, tools, or spare parts that are needed to advance space exploration, potentially using space dust or rock as a raw material. In-space manufacturing demonstrations on NASA have included initiatives like—The 3-D Printing in Zero G Technology Demonstration Mission, The Additive Manufacturing Facility (AMF), and Recycling in Space. As of spring 2023, NASA **has invested more than $60 million in more than 20 In Space Production Applications (InSPA**) awards to U.S. entities seeking to demonstrate the production of advanced materials and products on the ISS. These InSPA awards help the selected companies to raise the technological readiness level of their products and move them to market, propelling U.S. industry toward the development of a sustainable, scalable, and profitable non-NASA demand for services and products manufactured in the microgravity environment of Low Earth Orbit for use on Earth.

In June 2023, NASA chose around 300 proposals for 2023's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Phase I awards. Continuing the pattern of previous years, a significant number of projects center around 3-D printing. A noteworthy 25 projects were aligned with this focus, aiming to either develop new additive manufacturing (AM) processes or leverage existing 3-D printing technologies to support various NASA applications, missions, space exploration systems, and aeronautics. With a total agency investment of $45 million, each proposal team will receive $150,000 to demonstrate the promise and feasibility of their innovative ideas. In 2019, only 10 companies focusing on additive manufacturing were selected for Phase I awards. However, by 2022, this number had surged to 24 projects utilizing 3-D printing capabilities.

In December 2023, **DCUBED**, a German NewSpace hardware manufacturer, and the Hochschule München University of Applied Sciences were awarded funding for a joint research project by the Bavarian Ministry of Economic Affairs. The total value of the project amounts to **more than $1 million**, two-thirds of which is provided by the state. The first use case for ISM will be the manufacturing of support structures for satellite solar panels from photopolymer, using 3-D printing in space.

Chart 3: Thomas Sinn And Mike Kringer with In-Space Manufacturing Demonstration Payload

Source: Intro Act, DCubed

According to Strategic Market Research, the global aerospace 3-D printing market is poised for substantial growth, with a strong compound annual growth rate (CAGR) of 20.2%. In 2022, the market was valued at $2.1 billion, and it is projected to reach $10.8 billion by 2030. North America is anticipated to maintain its leadership position, representing 48.2% of global sales in the industry.

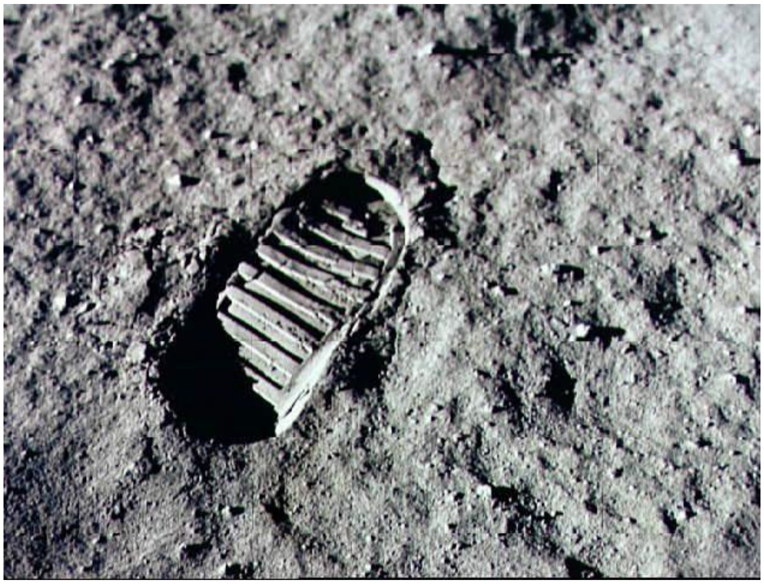
BENEFITS OF 3-D PRINTING OFF-WORLD

3-D printing is rapidly transforming the aerospace industry, emerging as a game-changer for space travel. Researchers are pioneering applications for this technology that extend beyond Earth. While 3-D-printed parts are already being delivered to the space environment, the future holds even greater promise. Advancements are underway in technologies that can 3-D print directly in the microgravity and vacuum of space. This concept, often described as “in-space manufacturing” or “additive manufacturing for space,” offers a multitude of benefits.

Cost Reduction: By manufacturing objects off-world, 3-D printing significantly reduces the costs associated with launching materials from Earth. Rocket weight is a big challenge when it comes to reaching outer space. To break free from Earth's gravity, you've got to zoom super-fast. The heavier your rocket, the harder it is to get out of the gravity well. That's why aerospace engineers are always trying to make rockets lighter. With 3-D printing, astronauts can make tons of material in space without having to bring everything with them. Need a bowl? Just print one! NASA just needs to send some 3-D printing materials, and astronauts can whip up whatever they need. 3-D printing can significantly reduce the weight of rockets, which is a critical factor in the cost and efficiency of space travel. 3-D printing streamlines rocket manufacturing by creating complex structures in single pieces, reducing the need for assembly. It enables optimized designs like honeycombed lattices, cutting down on mass and costs. For engine nozzles, it eliminates separate cooling systems, reducing weight. Lightweight materials further enhance performance and cost-effectiveness.

In-Situ Resource Utilization: Imagine building a house on the Moon, not with prefabricated parts, but by utilizing the lunar dust itself! This futuristic concept, as already noted, is In-Situ Resource Utilization, and it goes hand-in-hand with 3-D printing. Traditionally, almost everything needed for space missions—from habitats to tools—has been launched from Earth. This is incredibly expensive and limits the size and complexity of what we can build off-world. ISRU changes the game by allowing us to harvest resources directly from celestial bodies like the Moon or Mars. Lunar regolith, the dusty surface layer, is a prime candidate.

Chart 4: A Boot Print on Lunar Regolith



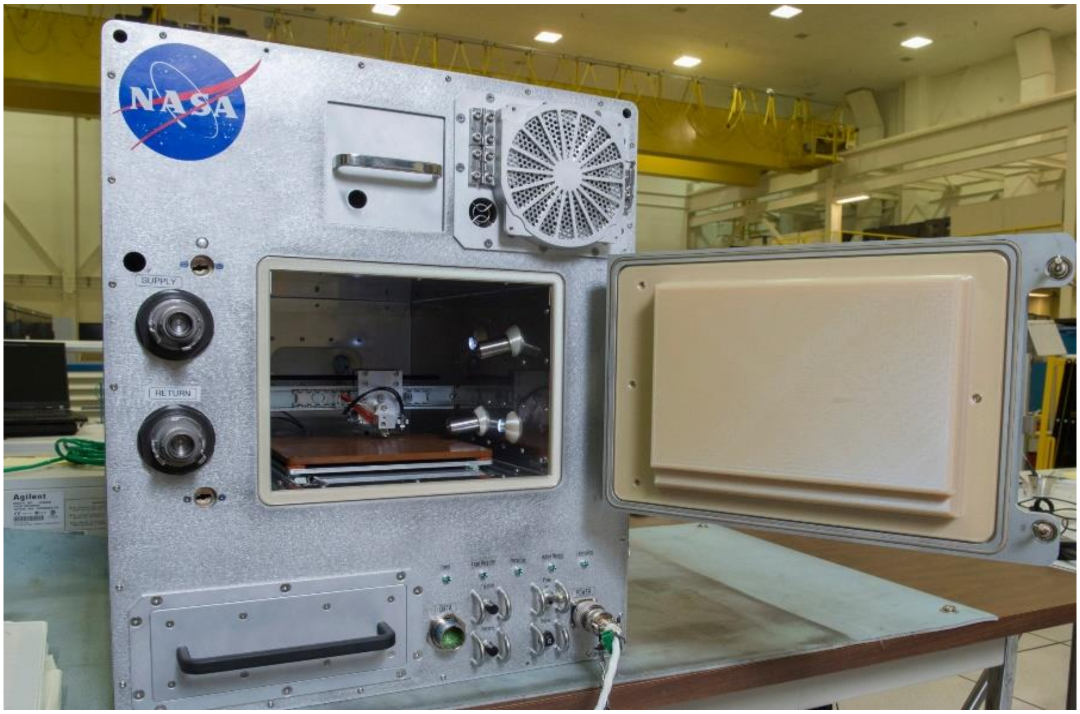
Source: Intro Act, Universe Today, NASA

Enhanced Mission Flexibility and Autonomy: The ability to produce what is needed, when it is needed, enhances mission flexibility and autonomy, reducing the risks associated with supply chain failures. 3-D printing allows for on-the-fly mission adjustments. Imagine needing to modify a scientific instrument or create a specialized bracket for a new habitat module. With 3-D printing, these adjustments become feasible, enabling crews to adapt to unexpected situations and optimize their mission objectives. 3-D printing empowers crews to solve problems and maintain their habitats and spacecraft with greater autonomy. They become less reliant on pre-determined supplies and mission support from Earth, fostering a sense of self-sufficiency and adaptability.

Effective Waste Management: Living in a confined space like a spaceship or lunar base presents unique challenges, one of which is waste management. Every scrap, every food wrapper, adds to the limited space and resources available. Here's where 3-D printing steps in, offering a solution for effective waste management through a process called **closed-loop manufacturing**. Astronauts no longer throw away broken tools or used plastic packaging. Instead, these waste materials are fed into a special 3-D printing recycler. This machine breaks down the waste, transforming it into usable filament for the 3-D printer.

The first recycling printer sent to the ISS, **the Refabricator**, has been on board for more than three years. It was designed to recycle 3-D-printed plastic into parts and tools that are then sent back to Earth for analysis to see how the recycling process affects the basic structure of the plastic. The Refabricator demonstrates technology developed by **Tethers Unlimited** to recycle waste plastic materials, including previously printed items, into high-quality 3-D-printer filament. It is essentially a recycler and 3-D printer in one unit, about the size of a dorm room refrigerator. It began operations on the space station in February of 2019.

Chart 5: The "Refabricator" is a Recycler and 3-D Printer in One Unit



Source: Intro Act, NASA

Innovation and Customization: 3-D printing allows for rapid prototyping and customization, enabling the design and production of complex structures that would be difficult or impossible to create using traditional manufacturing methods. It allows for the fabrication of unconventional shapes, such as intricate internal lattices and interlocking components, enhancing strength while minimizing weight. Traditional manufacturing often involves removing material to achieve intricate designs, resulting in heavier structures. However, 3-D printing builds objects layer-by-layer, incorporating internal voids and channels, producing robust yet lightweight designs crucial for space missions. Moreover, the iterative nature of 3-D printing enables rapid design modifications, facilitating ongoing optimization directly in space, and ensuring that structures meet the evolving needs of space exploration and development.

APPLICATIONS OF 3-D PRINTING IN SPACE EXPLORATION

Off-world 3-D printing holds immense potential for revolutionizing how we explore and live beyond Earth. Here's a breakdown of some exciting applications:

Building Habitats and Structures: As humanity eyes the establishment of communities on planets like Mars, 3-D printing offers a viable solution for constructing habitats using local materials. This process involves using regolith (the loose material covering solid rock) to create structures, significantly reducing the need to transport building materials from Earth. 3-D printed patches can be designed to fit the exact tear in a spacesuit or spacecraft hull, offering a faster and more efficient repair solution. Building with 3-D printers is significantly faster than traditional methods. This is crucial for establishing a foothold on celestial bodies. **ICON**, a construction technology company with over **$450 million** in funding, secured a **$57.2 million** contract from NASA in 2022. This award will support the development of what ICON is calling "**Project Olympus**," an ambitious plan to build structures on the Moon and Mars using in-situ resources. Olympus' printing technology processes local lunar regolith into a super strong building material using only energy and then 3-D-prints structures with it. This funding will keep the project alive for several more years at least: the contract **runs through 2028**.

Chart 6: Off-World Additive Construction

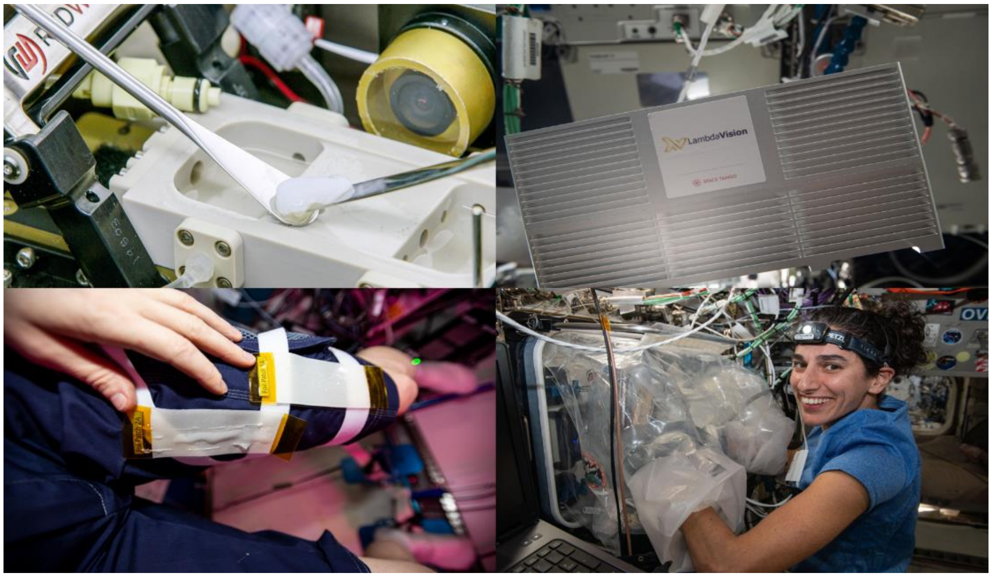
Source: Intro Act, ICON

Manufacturing Spare Parts and Tools: One of the primary applications of 3-D printing off-world is the manufacturing of spare parts and tools on-demand. This capability is crucial for long-duration space missions, where carrying a large inventory of spare parts is impractical. Astronauts can produce the required items on demand, reducing dependency on Earth and enhancing mission sustainability. Scientists can design and print unique tools and experiment apparatuses tailored to specific needs on a space mission. Think of a gripper designed to collect a specific lunar sample. 3-D printing allows for complex, lightweight structures that wouldn't be possible with traditional manufacturing. This translates to more efficient use of fuel and increased payload capacity for spacecraft.

Developing Human Organs and Tissue: In the realm of long-duration human spaceflight, the ability to 3-D print human organs and tissues could be transformative, offering solutions for medical emergencies.

Bioprinting is a specialized form of 3-D printing that uses human cells. In the future, it could be used to create custom tissues or even organs for astronauts in case of emergencies. **Redwire Corporation** developed the **BioFabrication Facility (BFF)** as a part of the larger goal of using microgravity to bioprint human organs. Bioprinting technology also could create artificial retinas to help restore sight for the 30 million people worldwide who suffer from degenerative retinal diseases. Protein-Based Artificial Retina Manufacturing is one of several investigations by **LambdaVision Inc.** in partnership with developer **Space Tango Inc.** to develop and validate space-based manufacturing methods for artificial retinas. Bioprint FirstAid, a study from **ESA** and the **German Space Agency (DLR)**, demonstrated the function of a prototype for a portable handheld bioprinter that creates a patch from a patient's own skin cells. Space causes changes in the wound healing process, and such customized bandages could accelerate healing on future missions to the Moon and Mars.

Chart 7: 3-D Bioprinted Knee Meniscus (Left), Protein-Based Artificial Retina Manufacturing (Right), Bioprint FirstAid (Bottom Left) and BioFabrication Facility (BFF) (Bottom Right)

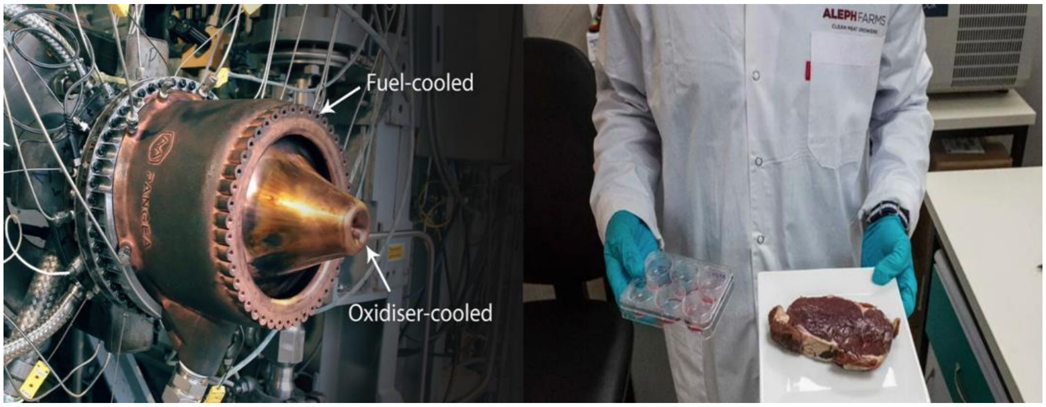


Source: Intro Act, NASA

Making Satellites, Thrusters, Rocket Engines, and Rockets: Additive manufacturing is becoming a prevalent method for constructing satellites. Major players like **Boeing** and **Airbus** are actively engaged in projects aimed at creating intricate and lightweight satellite components using this technology. Additive manufacturing and the materials it employs enable the creation of novel geometries, expanding possibilities in various applications. **Thrusters** represent one example of this application, benefiting from additive manufacturing techniques. **Astrobotic's Griffin Mission One (GM1)** team has partnered with **Agile Space Industries** to create custom 3-D printed thrusters for the Griffin lunar lander, known as **Attitude Control Thrusters (ACT).** To expedite the development of rocket engines, businesses are opting to modify their manufacturing processes, with many turning to 3-D printing. Utilizing this technology, companies have successfully produced and brought to market advanced combustion devices made from state-of-the-art materials. This innovation has led to the creation of 3-D-printed rocket engines that boast a 15% increase in efficiency compared to traditionally manufactured counterparts. An example of this is Spanish Company **Pangea**, which develops and industrializes advanced 3-D printed combustion devices made of innovative materials. In the aerospace industry, additive manufacturing isn't just limited to producing specialized parts; it's also being used to fabricate **entire 3-D-printed rockets**. This growing practice enables companies to reduce the weight of their final products. Space companies are now setting their sights on constructing fully 3-D-printed and reusable rockets capable of launching **payloads exceeding 20,000 kg into Low Earth Orbit.**

Preparation of Food Using 3-D Printing in Space: The aerospace sector is grappling with the challenge of developing 3-D-printed food. Recently, several companies have used 3-D technology to produce "space food." **Aleph Farms**, an Israeli start-up, announced its intention to **3-D print beef** within the International Space Station in 2019. Using Bioprinting Solutions' 3-D printer, they successfully created cell-based meat with the same texture, flavor, and structure as traditional steak. Bovine cells sourced from cows on Earth were transported to the ISS and cultivated there to achieve this feat.

Chart 8: Pangea Aerospace Manufactured Rocket Engine Using 3-D printing (left) and Creation of Cell-Based Meat Using Bioprinting Solutions' 3-D Printer (right)



Source: Intro Act, Pangea Aerospace, 3-DNatives, Aleph Pharms

Clothes for Astronauts: Additive manufacturing finds another application in space missions: the production of garments. Companies in this field have engineered 3-D-printed spacesuits and helmets that are easily replicable with 3-D printers. These suits are tailored for spaceflight, equipped with essential features such as visors, valves, locks, and microphones integrated into the helmets.

FUTURE OF 3-D PRINTING IN OUTER SPACE

3-D printing holds immense potential for aerospace applications, promising to become a crucial asset for future space travels. The pace of innovation and exploration in this field is accelerating, as researchers continually seek new ways to leverage this cutting-edge technology in space.

Two distinct avenues of application have emerged: **3-D printing within space stations** and **3-D printing outside of them**. Internally, 3-D printing offers significant advantages for astronauts, enabling them to address daily needs and emergencies by rapidly producing replacement parts and tools. Externally, the potential of additive technology extends to creating satellite structures directly in orbit. Integration of 3-D printers into nanosatellites opens up possibilities for **on-demand fabrication** of structures in space, showcasing the transformative capabilities of additive manufacturing in the aerospace sector.

Additional trends that will shape the future of 3-D printing in space include:

Advancement of Multimaterial 3-D Printing Technology—A notable advancement in 3-D printing is the capability for simultaneous multi-material printing, marking a departure from the previous limitation of printing with a single material per job. This breakthrough allows for the creation of intricate and functional objects with unparalleled precision. The advent of simultaneous multi-material printing is reshaping industries such as healthcare, robotics, and aerospace, where the demand for intricate designs and material versatility is paramount. In January 2024, **Sidus Space**, a space and data-as-a-service company, has introduced its new multi-material 3-D Printing Division. The company recently utilized MarkForged X7 printers and OnyxFR-A material to manufacture structural support components in its **LizzieSat satellite**, which is scheduled to launch on Transporter 10 after March 2024.

Chart 9: Multi-Material 3-D Printing Technology

Source: Intro Act, Revolutionized

Rise of Self-Sustaining Systems - Habitats with the ability to 3-D print additional modules would allow for expansion and adaptation over time. Recycling and reusing waste materials on board spacecraft for 3-D printing could become a reality.

Focus on Remote Printing and Collaboration - Teams on Earth and in space could collaborate on designs and remotely control the 3-D printing process for structures on other planets. This would allow for the combined expertise of engineers on Earth with the real-time input of astronauts in space. Imagine engineers on Earth using shared online platforms to design components or structures needed off-world. Communication technologies like high-speed space Internet will enable real-time communication between design teams on Earth and astronauts in space. This allows for feedback and modifications before printing commences.

Digital Libraries - Creating digital libraries of pre-approved and tested 3-D printable components for spacecraft could streamline the design process. Astronauts could choose components from the library and adapt them for specific needs, reducing design time and ensuring compatibility. 3-D printers can be equipped with sensors to monitor printing progress, material flow, and quality in real-time. The data can be transmitted back to Earth, allowing remote teams to oversee the printing process and identify any potential issues. **Artificial intelligence** could be integrated into 3-D printing systems for intelligent material selection, process optimization, and even automated repairs or maintenance. This would further enhance the efficiency and reliability of 3-D printing beyond Earth.

The space technology and 3-D printing industries are poised for substantial growth in the near future, fueled by several key factors. These include **rising government investments** in space exploration, escalating **demand for satellite services**, and the **emergence of new space-based applications** like space tourism and mining. Additionally, the **decreasing cost of 3-D printing technology** is expected to further propel the expansion of these industries.

CHALLENGES

While space 3-D printing sounds good on paper, there are various challenges that still must be considered for printing-assisted space missions. The conditions in outer space are drastically different from those on Earth. This includes factors such as the absence of gravity, radiation, and rapid changes in temperature.

Microgravity Printing:

Traditional 3-D printing techniques rely on gravity to help materials settle and bond properly. In the microgravity environment of space, this becomes a significant hurdle. Material properties need to be adapted, and printing processes may require modifications to ensure successful creation of strong and functional objects.

Limited Printing Materials:

Currently, most space printers use plastics, which are good for some applications but not strong enough for everything. Research is ongoing to explore a wider range of materials like metals, lunar regolith (Moon dust), or even recycled waste on board the spacecraft. However, adapting printing processes for these materials presents a challenge.

Technical Complexities:

Metal 3-D printing, while highly desirable for stronger structures, often requires larger and more energy-intensive machines compared to plastic printers. Miniaturization and optimizing power usage are crucial for wider adoption in spacecraft with limited space and power resources.

Quality Control and Maintenance:

In the harsh environment of space, with limited resources and personnel, ensuring the quality and functionality of 3-D printed objects becomes critical. Developing reliable in-situ quality control and maintenance procedures for 3-D printers is essential.

Safety Considerations:

The process of 3-D printing can generate dust and fumes, which could pose a health hazard for astronauts in a closed environment like a spacecraft. Developing safe printing methods and proper ventilation systems is crucial.

Overall, overcoming these challenges is crucial for unlocking the full potential of 3-D printing off-world. As research and development progress, we can expect advancements in materials, printing techniques, and overall system integration, paving the way for a future where 3-D printing plays a vital role in space exploration and beyond.

LEADING COMPANIES IN 3-D PRINTING

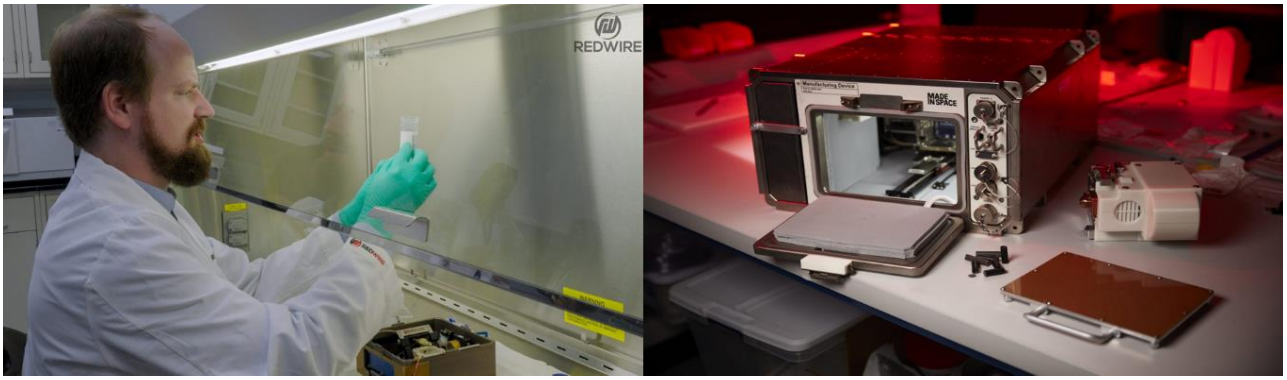
Made in Space (acquired by **Redwire Corp**.), **Relativity Space**, and **AI SpaceFactory** are the leading companies in the 3-D printing segment. With the addition of **Vaya Space**, the list provides a more comprehensive overview of the companies that are pioneering the use of 3-D printing technology in the realm of space exploration and development, showcasing the diverse applications and innovative strategies being employed in this exciting field.

Redwire Space (NYSE: RDW)

Redwire is a leader in space infrastructure and has made significant advancements in 3-D printing technologies for space applications. Its work includes developing 3-D printers capable of operating in outer space and manufacturing components for satellites and other spacecraft. **In June 2020, it acquired Made in Space,** which is a pioneer in space manufacturing and is specialized in developing 3-D printers for use in the microgravity environment. Its technology has already been deployed on the International Space Station for various manufacturing tasks. Redwire's 3-D printing operations are primarily under Made in Space.

The **Redwire Regolith Print (RRP) Mission**, led by Made in Space, aimed to demonstrate the feasibility of 3-D printing with simulated lunar regolith in microgravity, showcasing the potential of In-Situ Resource Utilization for space construction. Launched in August 2021 aboard the NG-16 commercial resupply mission to the International Space Station, the project utilized modified 3-D printer heads and print bed surfaces to work with the regolith simulant. The mission marked the first instance of lunar regolith simulant being used for 3-D printing in space, validating essential functionalities and laying the groundwork for future lunar construction endeavors. The RRP mission contributes to NASA's efforts in developing critical In-Situ Resource Utilization capabilities for the Artemis program.

Chart 10: Redwire Prints First Human Knee Meniscus on ISS; Redwire Regolith Manufacturing Technology



Source: Intro Act, Redwire Space

Redwire has made **significant advancements for in-space bioprinting** with its **3-D BioFabrication Facility (BFF)**, which is now permanently installed on the ISS. In late January 2023, NASA astronauts successfully installed an upgraded BFF that allows greater temperature control during bioprinting with sensitive bioinks The BFF is equipped with the Advanced Space Experiment Processor, which works in conjunction with the bioprinter. The BFF's mission was to produce a full 3-D printed human knee meniscus using bioinks. In September 2023, Redwire Space succeeded in this pioneering achievement.

In 2023, Redwire's **revenue increased by 51.9% to $243.8 million** compared to 2022, while it **reduced net loss to $27.3 million** from $130.6 million in 2022. Contracted backlog also grew by 19.1% to $372.8 million by the end of 2023. FactSet predicts a **22.8% revenue growth in 2024**, reaching $299.4 million, with an estimated net loss decrease to $14.8 million and a loss per share of $0.33 compared to $0.42 in 2023. The company's stock is currently **trading at attractive valuations**, with a P/S ratio of 0.76 and EV/Sales ratio of 1.47x. With **promising revenue growth** and **expected financial improvements**, Redwire Space presents a compelling investment opportunity.

Relativity Space

Leveraging 3-D printing technology, Relativity Space is revolutionizing how rockets are built. The company's ambitious goal is to 3-D print most of its rocket components, aiming to streamline production and increase flexibility in rocket design. It is doing so by harnessing additive manufacturing, artificial intelligence, and autonomous robotics. Through its proprietary “Factory of the Future,” anchored by **Stargate, the world’s largest metal 3-D printers**, it can design and produce intricate, large-format components with unprecedented precision and speed. By minimizing fixed tooling and reducing part count, Relativity accelerates design iteration and optimization, while ensuring real-time quality control through sensor-driven analytics and machine learning.

Unlike companies utilizing 3-D printing for specific components, Relativity Space aims to transform rocket manufacturing by **3-D printing entire launch vehicles**. Its flagship rocket, **Terran 1**, is the world’s first fully 3-D-printed rocket designed to reach Low Earth Orbit. Continuing its upward journey, Relativity Space is in the **process of launching Terran R**, designed to meet the needs of commercial and government entities sending payloads into LEO, MEO, and GEO. Terran R harnesses the power of Relativity Space’s advanced 3-D-printed Aeon R engines to achieve peak propulsion efficiency. Through its exclusive 3-D printing methodologies, the company maximizes engine functionality while minimizing material usage, resulting in cost-effective solutions. **Intelsat**, a leading satellite operator, has entered **into a multi-year, multi-launch agreement with Relativity Space** for the deployment of its Terran R reusable launch vehicle. The agreement, announced on October 11, 2023, entails multiple launches of Intelsat satellites using Terran R, with the first launch slated for no earlier than 2026, aligning with Relativity's projected debut of the Terran R.

As of today, Relativity Space has raised a total of $1.3 billion in funding over eight rounds with a post-money valuation of around $4.2 billion in 2021. FactSet estimates its 2023 revenue to be around $135.25 million. Overall, Relativity Space's **pioneering approach to 3-D printing entire rockets** has the potential to disrupt the aerospace industry.

Chart 11: Building of Terran 1 Rocket - The First 3-D Printed Rocket

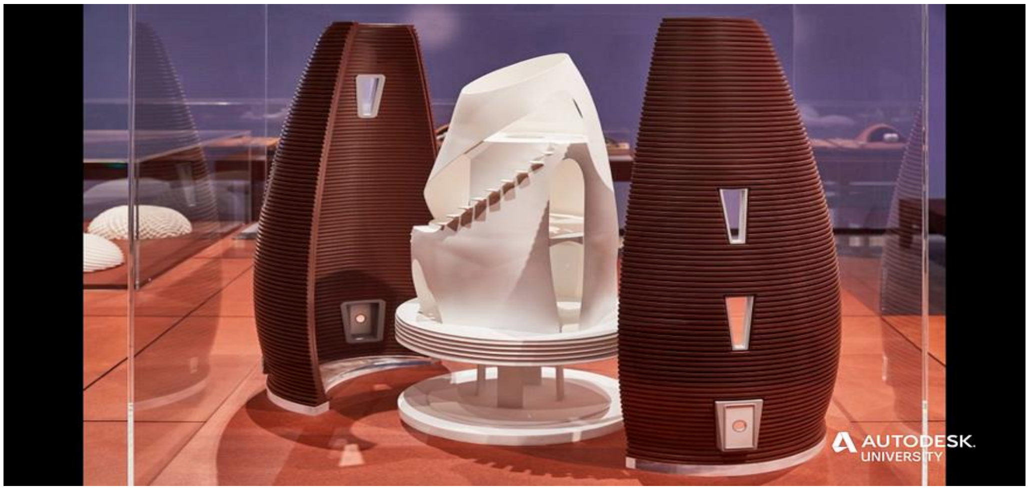
Source: Intro Act, Relativity Space

AI SpaceFactory

Specializing in the construction of habitats on Mars and the Moon, AI SpaceFactory uses 3-D printing technology to create sustainable and durable structures from materials found on these celestial bodies. Its team of architects and engineers participated **in NASA's 3-D Printed Habitat Challenge in 2018-2019**, where its design, **MARSHA**, a Martian habitat**, won 1st place for its human-centric spaces** and pioneering use of materials. Following this success, the company initiated the **TERA** (Terrestrial Analog) project in 2020, showcasing an eco-friendly 3-D-printed dwelling made from sustainable materials, highlighting the potential of technology to reduce waste and carbon footprint in construction. Collaborating with NASA from 2021 to 2023, AI Space Factory developed **LINA** (Lunar Infrastructure Asset), an in-situ 3-D-printed outpost to protect astronauts and critical missions on the Moon.

In January 2023, AI SpaceFactory introduced its pilot robotic arm 3-D printer, ASTRA, evolving from the prototype developed for the NASA Centennial Challenge. Engineered for scalability, simplicity, and sustainability, ASTRA aims to empower the next generation of builders and creators by utilizing recycled 3-D print materials, automated tool-path algorithms, and an intuitive interface. SpaceFactory plans to launch a series of large-format gantry-style 3-D printers, including the T200 "Starforge", leveraging technology from its NASA partnership. These modular printers are poised to revolutionize various industries by facilitating the production of intricate parts, streamlining operations, and unlocking unprecedented efficiencies. AI SpaceFactory stands as a prominent innovator in sustainable space architecture. Its dedication to 3-D printing, ISRU, and eco-friendly design principles paves the way for a future where humanity can establish a sustainable presence on other celestial bodies.

Chart 12: AI Spacefactory's Structure MARSHA Won the NASA 3-D-Printed Habitat Challenge



Source: Intro Act, Medium

CONCLUSION

In conclusion, 3-D printing is playing a pivotal role in shaping the future of space exploration and development. By enabling on-demand manufacturing, reducing reliance on Earth-based resources, and fostering innovation, this technology is paving the way for sustainable and efficient space operations that were simply not possible in the past. The companies mentioned above are at the forefront of this technological revolution, driving advancements that will expand humanity's presence in space.

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