National Aeronautics and
Space Administration

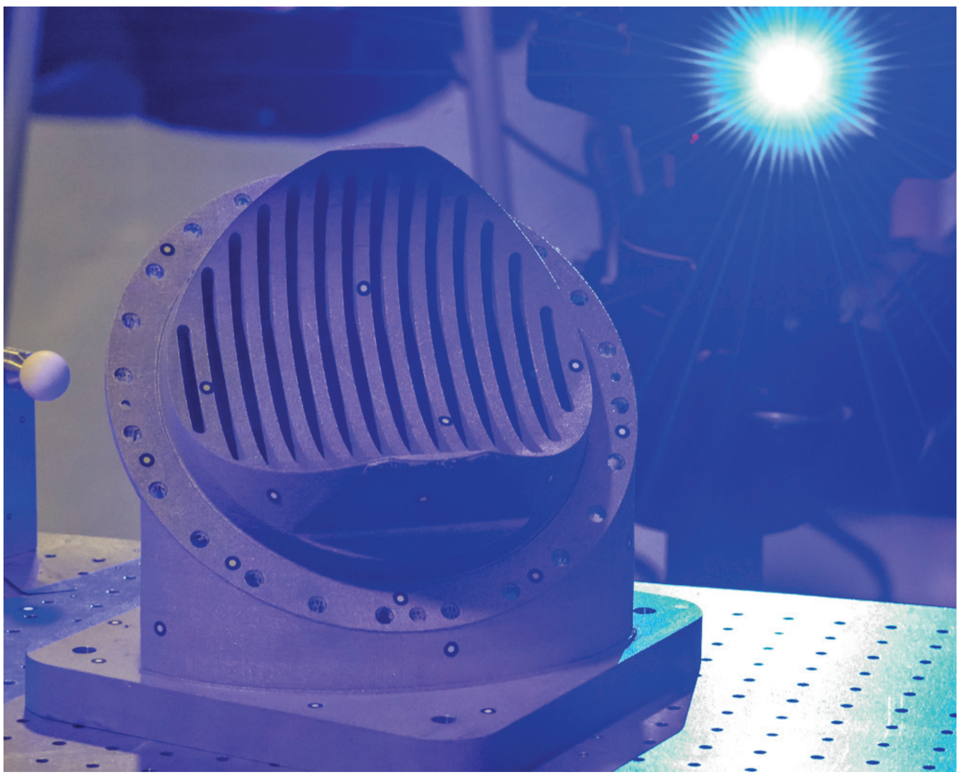
Additive Manufacturing

Pioneering Affordable Aerospace Manufacturing

Rapidly evolving digital tools, such as additive manufacturing, are the leading edge of a revolution in the design and manufacture of space systems that enables rapid prototyping and reduces production times. Marshall has unique expertise in leveraging new digital tools, 3D printing, and other advanced manufacturing technologies and applying them to propulsion systems design and other aerospace materials to meet NASA mission and industry needs. Marshall is helping establish the standards and qualifications "from art to part" for the use of these advanced techniques and the parts produced using them in aerospace or elsewhere in the U.S. industrial base.

At-A-Glance

Propulsion system development requires new, more affordable manufacturing techniques and technologies in a constrained budget environment, while future in-space applications will require in-space manufacturing and assembly of parts and systems. Marshall is advancing cutting-edge commercial capabilities in additive and digital manufacturing and applying them to aerospace challenges. The Center is developing the standards by which new manufacturing processes and parts will be tested and qualified.

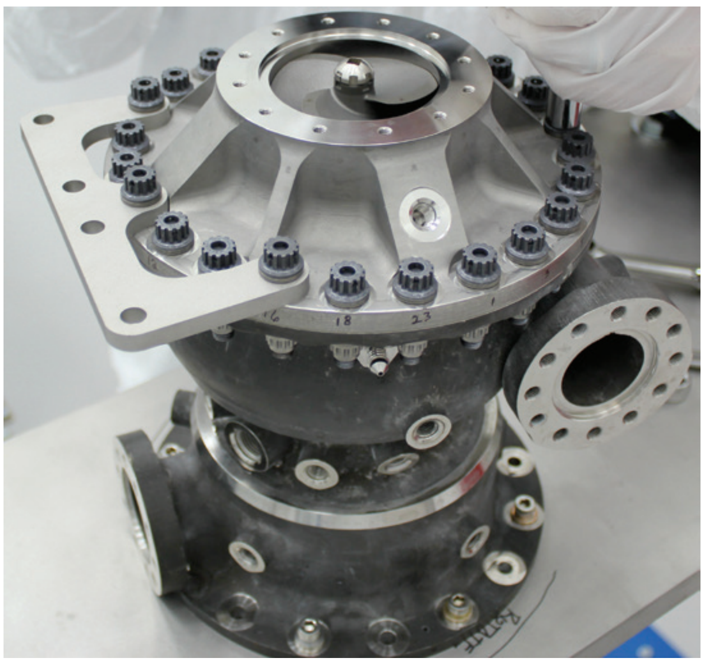


Selective laser melting enables faster and cheaper component development.

Accelerating Design and Development for Plastics and Metals

As designers harness the capabilities of Additive Manufacturing, the way they think is changing. The ability to rapidly create and test prototypes saves significant time, as design concepts can quickly advance from drawings to test articles. A propulsion system sub-assembly that previously required multiple welds might now be 3D printed as one piece and test-fired in less time and at much less cost than traditional manufacturing. A combination of experienced engineers and in-house resources enables Marshall to take a project from conception through manufacturing, finishing, and testing, resulting in flight-ready hardware and/or proven processes for use by partners during full-scale production.

As Additive Manufacturing first emerged in 1990, Marshall used one of the first printers for rapid prototyping. Today, the Center is using state-of-the-art 3D printers that work with a variety of plastics and metals.



This rocket engine fuel pump has hundreds of parts including a turbine that spins at over 90,000 rpm. This turbopump was made with additive manufacturing and had 45 per cent fewer parts than pumps made with traditional manufacturing.

Additive Manufacturing technology for plastics includes:

- Stereo-lithography: often used for flow cell models and cold flow testing, as the parts are water resistant and can be made see-through to channels inside:
- Fused Deposition Modeling: an extrusion-based technology that is gravity-independent and holds potential for development of in-space manufacturing

Additive Manufacturing technology for metals includes:

- Selective Laser Melting (Direct Metal Laser Sintering)
- Electron Beam Melting

Marshall's capabilities for 3D printing metals includes titanium, aluminum, Inconel and other nickel alloys widely used in aerospace manufacturing.

Additive Manufacturing For Space

Additive Manufacturing is a key technology for enhancing space vehicle designs and enabling affordable missions. The additively manufactured components' ability to withstand extreme temperatures and highly pressurized environments could bring significant time and cost savings for propulsion systems. Marshall's current focus is on the future affordability of SLS engines, and on evaluating additively manufactured components for use in potential methane-based human in space and lander propulsion systems

Marshall teams are testing the characteristics of additively manufactured turbopumps, injectors and other engine components. Tests have evaluated 3D printed parts with engine thrust class and propellants within performance parameters applicable to configurations of the SLS to the in-space propulsion requirements of landers. These efforts are paving the way for advancement of 3D printing of complex rocket engines and more efficient production of future spacecraft.

Additive Manufacturing In Space

While new spacecraft and propulsion technologies promise higher payload capacities and fuel efficiencies, in-space manufacturing can reduce the energy required to move a large amount of mass into space. Marshall is leading efforts to demonstrate 3D printing technology in orbit — the first step toward harnessing resources at an exploration site, also known as in-situ resource utilization.

In-situ resource utilization, whether on orbit or at exploration destinations, is a critical need for future long-duration and deep-space missions. It can take months or even years, depending on the launch resupply schedule, to get equipment to space, and for exploration missions, resupply from Earth may be impossible.

The International Space Station's 3D printer, receiving commands from the Payload Operations Integration Center, has manufactured the first 3D printed object in space, paving the way to future long-term space expeditions.

Regolith, the fine dust covering the moon, Mars, or other destination, can be a material source for 3D printing. Marshall scientists and engineers are studying the processes for and properties of construction material made from in-situ resources.

Digital Scanning for Manufacturing

Marshall houses a complete suite of digital manufacturing and support capabilities, including Structured Light Scanning, Non-Destructive Evaluation, Manufacturing Simulation, Manufacturing Planning and Execution, and inspection and machining technologies.

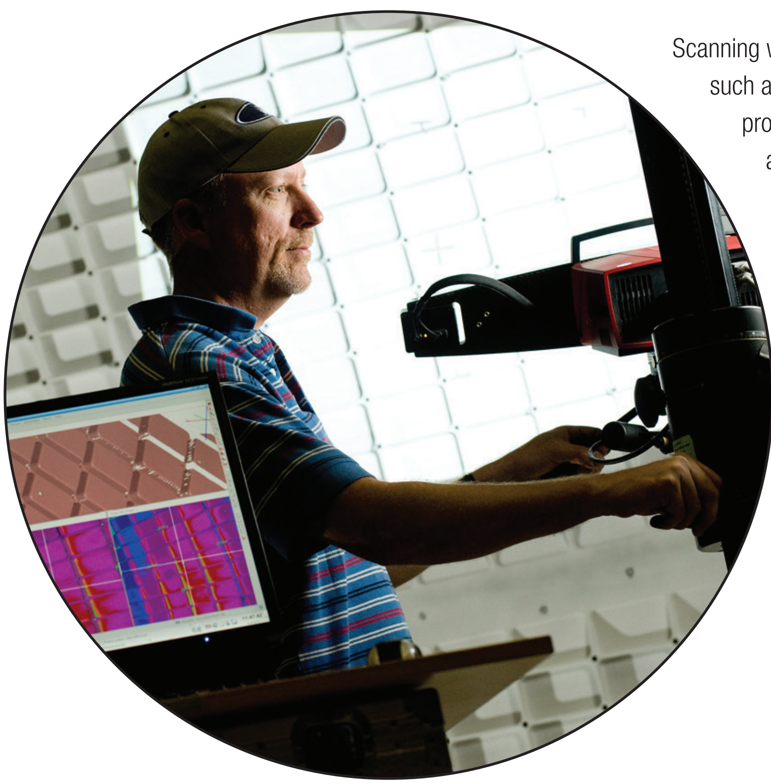
Structured Light Scanning is used to evaluate parts produced by 3D printers or other methods. With this technology, additively manufacture hardware can be accurately measured and compared to the original computer design. Marshall teams working on two Orion Multipurpose Crew Vehicle Stage Adapters used it to determine the precise cuts of large panels to shape the 18-foot-diameter cone. These technologies saved millions of dollars on custom tooling.

Structured Light Scanning technology includes:

- One Blue Light "Triple Scan" and other Blue Light 3D Scanners
- White Light 3D Scanners

The capability allows for scanning almost anything, from items smaller than a dime to the size of a Boeing 747. It has been used to scan 40-foot-diameter barrel sections of a space shuttle external tank and Space Launch System tank sections. The technique was also used to scan heritage F-1 engines, and the scans were then used to fabricate needed tooling to disassemble the engine for testing.

Scanning works in concert with other digital manufacturing techniques such as manufacturing simulation to identify and address potential problems early in the design and production process, saving time and costly re-tooling or repair. The expertise and software available at Marshall can provide virtual fit checks, predict the buildup of material on a surface, reverse engineering, kinematic analysis, and much more.



Structured Light Scanning of Orion panels allows extremely precise fits, saving millions of dollars on custom tooling.

Making Things In Space Will Reduce Future Payload Costs

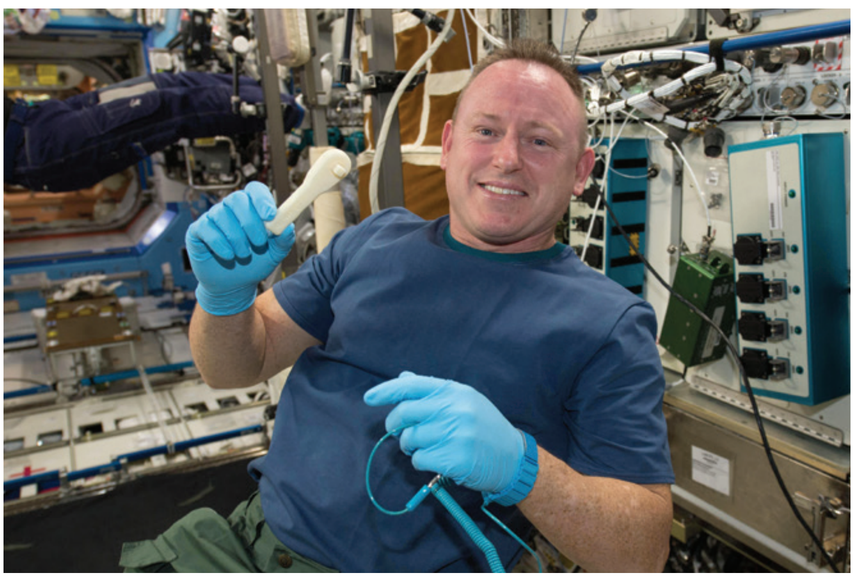
Spaceflight crews have always had to carry everything they might need with them or wait weeks or months for a cargo resupply mission to bring a replacement for a broken or lost part or tool. As humans begin to explore the solar system, we must move beyond dependency on Earth, minimizing logistical requirements to operate independently from Earth for extended missions into deep space.

Now, thanks to the Small Business Innovation Research (SBIR) program, Made In Space and Marshall have begun to bridge the gap in the supply chain between Earth and the International Space Station with a customized 3D printer that can perform in-space manufacturing of tools or parts. The printer uses a process known as additive manufacturing to heat a plastic filament and build it layer by layer to create the 3 dimensional object specified in the design file. Files can be loaded onto the machine prior to launch or they can be uploaded to the printer from Earth while it is in orbit.

The Made In Space printer was installed in November 2014 and has printed more than 20 items including a wrench, which was the first tool built in space. These parts were returned to Earth in February 2015 where they are being studied in comparison to a control group of identical parts made on the same printer before it was delivered to the ISS. The goal of this analysis is to verify that the 3D printing process works the same in microgravity as it does on Earth.

Future plans for Made In Space include exploring the possibilities of creating objects, such as nanosatellites, in space and then launching them into low orbit directly from the ISS. Nanosatellites are small shells that can carry any number of technologies or experiments. Printing these at the ISS could drastically alter the entire realm of nanosatellites. No longer having to wait for a scheduled launch from Earth, and securing the space on that launch to transport the secondary payload with save immensely in both time and resources.

In-space manufacturing is vital for long-duration missions and sustaining human exploration of other planets where there is extremely limited ability to resupply Earth-based products.



Printing needed tools in space can reduce reliance on resupply missions from Earth.

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