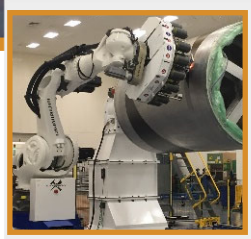
National Aeronautics and Space Administration

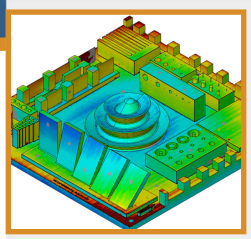
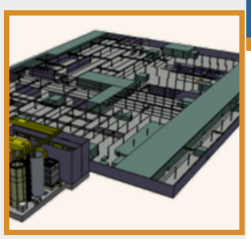
# Marshall Space Flight Center
# Advanced Manufacturing

**Engineering Solutions for Space Science and Exploration**


Additive Manufacturing



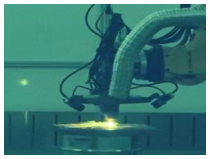

Composites Manufacturing

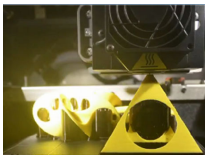
Digital Manufacturing

## Additive Manufacturing

capability at Marshall Space Flight Center (MSFC) has taken on a superior ranking in terms of world class manufacturing. Complex machining can now be reduced for much of a liquid rocket engine's subassemblies and other flight hardware as selective laser melting (SLM) and Directed Energy Deposition (DED) development continues to take place. MSFC is heavily involved in the field of additive manufacturing (AM) certification, developing industry AM standards to ensure process control and continued product integrity. MSFC continues to expand collaborative partnerships across industry and academia as AM technology continues to advance at a rapid pace. AM has significantly reduced the cost and time (between 40-80% depending upon the shape of the part and material) to manufacture parts.



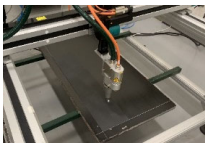
Directed Energy Deposition



Fused Deposition Modeling

Stereo Lithography

SLM

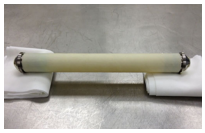


Automated Surface Preparation

SLS Payload Adapter

## Composites Manufacturing

capabilities in the Materials and Processes Laboratory at MSFC include state-of-the-art equipment and facilities coupled with extensive experience and expertise. Key infrastructure includes a modern automated fiber placement (AFP) system capable of precise and repeatable composite layups for large-scale structures; multiple filament winders ideal for composite overwrapped pressure vessel (COPV) and solid rocket motor (SRM) case production; and multiple autoclaves and ovens suitable for a range of composite structure scales. Composites manufacturing personnel work closely with design, analysis, and testing groups to bring composite structures from concept to reality. Together, these capabilities are unique within the Agency with respect to composite structures development.

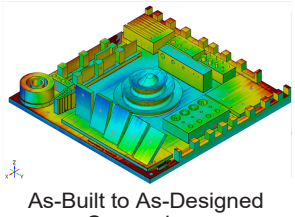


Composite Strut

Composite Chamber

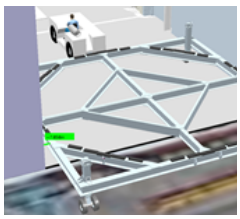
## Digital Manufacturing

capabilities located within MSFC's Materials and Processes Laboratory provide various services that span the entire product life cycle. The Laboratory's three major digital manufacturing capabilities are manufacturing simulations, manufacturing execution systems (MES), and structured light scanning. Our manufacturing simulation tools focus on the design, development, and manufacture of a product, optimize manufacturing operations and identifying and correcting problems early in the lifecycle. Our MES tools offer configuration control of process plans, control work on the shop floor, and capture the asbuilt data record. Our structured light scanning tools allow for accurate 3D measuring of as-built parts, developing parametric models, producing machining methods and digital assemblies of as-built components. The Laboratory's digital manufacturing capability is dedicated to developing, improving, and delivering the advanced processes and digital solutions needed to meet NASA's various goals and missions.



As-Built to As-Designed Comparison

Structured Light Scanning



Facility Verification

MES on Shop Floor

# Capabilities

## Additive Manufacturing

- Expertise in the design and manufacture of plastic and metallic AM components.
- Heavily focused on flight hardware development and alloy characterization for SLM and DED.
- Provide AM technical expertise and guidance through partnerships and collaborations with outside organizations.
- Heavily focused on AM certification and working with industry partnerships to enhance AM technology.




**SLA** High resolution with a quick turnaround time. Build volume up to 508 x 508 x 584 mm

**FDM** Variety of high strength materials. Build volume up to 914 x 609 x 914mm

**SLM** is primarily used for flight hardware development and alloy characterization. SLM is the primary candidate AM technology for liquid rocket engine modernization and AM certification efforts. Build volume up to 400 x 800 x 500 mm

**DED** is the latest addition to our AM equipment portfolio, enabling rapid production of large scale, near-net shape hardware. Build volume up to 12 x 8 x 10ft

## Composites Manufacturing

The composites manufacturing group at MSFC enables the complete product development of a wide range of composite structures for a variety of space applications. From technology development to flight hardware production, the composites manufacturing group at MSFC is highly capable partner in composite structures development.

### Key Facilities and Equipment:

- 10,000-ft$^2$ clean work area suitable for manufacturing of composite structures up to 18-ft diameter
- 5,000-ft$^2$ clean room suitable for assembly and integration of structures up to 27.5-ft diameter
- Automated fiber placement (AFP) system with ½-in and ¼-in slit tape heads, rotator assembly capable of accommodating tooling up to 12-ft diameter and 35-ft long, and accompanying laser projectors and laser tracker
- Two four-axis filament winding machines outfitted with state-of-the-art fiber tensioning systems capable of using wet winding and slit tape for producing structures up to 4-ft diameter and 15-ft long
- Three autoclaves: 18-ft × 20-ft. (up to 350 psi and 400°F), 9-ft× 12-ft. (up to 150 psi and 600°F), and 4-ft × 6-ft. (up to 240 psi and 650°F)
- Multiple ovens, from 4-ft × 8-ft to 20-ft × 6t
- Multi-zone hot bonder capable of 350°F cures, along with a range of accompanying heat blankets of various sizes

## Digital Manufacturing

### Structured Light Scanning and Photogrammetry:

Structured light scanning provides an accurate 3D surface representation of as-built hardware. This technique is capable of capturing parts less than 1 inch in length and, with the aid of photogrammetry, parts larger than 60ft in length. Photogrammetry uses images to capture 3D locations of reference points in space enabling the structured light capture of large hardware.

### Digital Manufacturing Simulations:

Our digital manufacturing tools provide a way to generate three-dimensional manufacturing simulations. Several analyses are performed that allow for problems to be identified early in the design cycle. Such as:

- Verification of facilities
- Interference analysis
- Kinematic verification
- Off-line robotic programming

### Manufacturing Execution System:

It is important to maintain configuration control of process plans and to capture all critical data that is used, generated, or created on the floor. Our MES provides a robust way to conduct process planning, process execution, and enforce process quality. Some notable features include configuration control of process plans, eBOM to mBOM planning, effectivity, model-based instructions (MBIs), capture as-built data, electronic buy offs, redlining of plans, discrepancy capture, and electronic buy offs.

**For more information, please visit www.nasa.gov/centers/marshall/about/business.html**

Contact:
Chad Hastings
EM42 Advanced Manufacturing Branch MSFC
Materials & Processes Laboratory Email:
william.c.hastings@nasa.gov
Phone: (256) 961-1535

National Aeronautics and Space Administration
**George C. Marshall Space Flight Center**
Huntsville, AL 35812
www.nasa.gov/marshall

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