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Large 3-D Printed Rocket Injector Roars To Life During Hot-Fire Test

By Tracy McMahan

The largest 3-D printed rocket injector NASA has ever tested blazed to life generating a record 20,000 pounds of thrust during a successful hot-fire test in a NASA test stand on Aug. 22.

Early data from the test conducted at pressures up to 1,400 pounds per square inch absolute and at almost 6,000 degrees Fahrenheit -- typical of the environments experienced by rocket engines -- indicates the



Test engineer Ryan Wall, left, and propulsion systems engineer Greg Barnett prepare a rocket injector made using the 3-D printing or additive manufacturing process for a hot-fire test at NASA's Marshall Space Flight Center. The injector was tested on Aug. 22, at Marshall Test Stand 116 in the East Test Area. (NASA/MSFC/Emmett Given)

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Greening Marshall: A Healthy Environment Means a Healthy Workforce

By Bill Hubscher

"We're here to keep the environment healthy and our people out of trouble."

It may be over-simplifying, but that statement from Donna Leach, sustainability coordinator with the Marshall Space Flight Center's Environmental Engineering & Occupational Health Office, or



Amy Keith, an engineer with the Marshall Center's Environmental Engineering & Occupational Health Office, performs a biological assessment in Indian Creek in Madison County, Ala., for the Marshall Space Flight Center. (NASA/MSFC)

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Hot-Fire Test *Continued from page 1*

injector worked flawlessly. During the hot-fire test, liquid oxygen and gaseous hydrogen flowed through the injector into a combustion chamber producing 10 times more thrust than any injector ever fabricated using a process known as additive manufacturing, or 3-D printing.

“We are learning what it takes to build larger 3-D parts from design to manufacturing to testing,” said Greg Barnett, an engineer for the project in the Propulsion Systems Department at NASA’s Marshall Space Flight Center. This was Barnett’s first time to lead a test. “It was fun to work on this injector through the whole process from conception to seeing it come to life on the test stand. To bring down the cost of building launch vehicles, this knowledge can be applied to any of NASA’s Space Launch System’s engines or to rocket components being built by industry.”

While an injector is not the biggest part of a rocket engine, it performs the critical job of efficiently delivering propellants that power the engine and provide the thrust necessary to send launch vehicles to space. The 9.5-inch-diameter, 6-inch-tall subscale injector is similar in size to injectors that power small rocket engines and similar in design to injectors for large engines, such as the RS-25 engine that will power the Space Launch System.

“Many of our young engineers are helping us evaluate how the process of additive manufacturing can add flexibility to every phase of developing space hardware,” explained Mary Beth Koelbl, deputy manager for the Engineering Directorate’s Propulsion Systems Department. “They are the ones who will be using this new process to build hardware that helps NASA reduce the risks and costs associated with space exploration.”

One of the keys to reducing the cost of rocket parts is minimizing the number of individual components that have to be built and assembled. This injector had only two parts, whereas a similar injector tested earlier had 115 parts.

“We took the design of an existing injector that we already tested and modified the design so the injector could be made with additive manufacturing.”



A 3-D printed rocket part blazes to life during a hot-fire test designed to explore how well large rocket engine components withstand temperatures up to 6,000 degrees Fahrenheit and extreme pressures, typical of the environments experienced by rocket engines. This injector was the largest 3-D printed rocket part NASA has tested to date. (NASA/David Olive)

explained Brad Bullard, a propulsion engineer responsible for the design of the injector. “Since we already tested the injector made with welds, we will be able to directly compare test data for both injectors to see if there’s any difference in performance.”

A commercial company manufactured the injector using selective laser melting, which sintered a powder of nickel-chromium alloy, often referred to by the trade name Inconel, in layers to make the complex injector with 28 elements for channeling and mixing fuel and oxidizer in just two pieces.

“Our ultimate goal is not to prove one part can survive a hot-fire test,” explained Ken Cooper, the lead for additive manufacturing at the Marshall Center. “What we are doing through a series of tests is learning about this new fabrication process and showing these parts can perform in a flight-like environment. NASA will share the data to boost American manufacturing know how.”

Watch [this video](#) to learn how Marshall Center engineers designed and tested a large 3-D printed rocket engine part.

McMahan is a public affairs officer in the Office of Strategic Analysis & Communications.

Greening Marshall *Continued from page 1*

EEOH, is accurate. The environmental team considers itself a support office ensuring the center follows environmental regulations set by the state and federal governments.

In the 1970s, the federal government recognized the need to protect the environment as a benefit to the general public. Prior to that at the Marshall Center, this was the responsibility of two staff members in the Office of Center Operations. Today, the team has grown to a staff of 13 civil servants in their own department and dozens of support people around the center concerned with the health and well-being of the NASA workforce as well as the facilities in which they work.

This means safely dealing with hazardous chemicals and waste, protecting ground water, air quality and safe disposal of toxic chemicals.

“We have two major roles at Marshall,” says Ed Kiessling, manager of the EEOH Office. “We perform inspections, monitoring and necessary cleanup as a result of actions from the past, and we ensure compliance with the country’s environmental protection laws to avoid these problems for the future. Our Environmental Management System is in place to protect us all.”

Part of the constant vigilance includes understanding the rules and requirements from the government and informing the center about new policies.

“New federal and state laws or amendments are released all the time,” says Dan Adams, compliance team lead with the EEOH. “Part of our mission is to inform our workforce and ensure everyone follows them. Marshall employees should be aware if their work or projects have any environmental impact.”

Employees also are required to understand the policies in place to keep the Marshall Center compliant with regulations by using the SHE 102 training modules in the online SATERN learning system. SHE 102 is a required online class containing various scenarios and lessons about environmental concerns unique to the Marshall

Living Green: Suggestions from EEOH to Help Our Environment

Energy Conservation: Conduct meetings via telephone or videoconference and share documents electronically instead of travelling to meetings and handing out reams of paper. Turn off lights, lamps, fans or computers in unoccupied offices.

Cleaning fluids: Find organic cleaning chemicals without toxins or allergens instead of using harsh chemicals that can flow into public waterways.

Vehicles: Try carpooling or alternative fuel vehicles. The Marshall Center even offers recharging stations (and good parking spots) for some electric cars.

The EEOH says if the Marshall Center can lead this effort, we come away helping the agency.

Center.

“Sustainability is a major emphasis for us right now, starting right at the top with center management,” Leach says. “When Marshall employees are proactive about recycling, green purchasing and energy & water conservation at the office, their behaviors reflect the center’s commitment to sustainability and aid in compliance with federal mandates.”

The EEOH Office considers proactive steps the center and its workforce can take, as well as compliance with government regulations, including finding environmentally friendly ways to dispose of refreshed computers and mobile phones or, better still, find other uses for them.

For more information about environmental management, Marshall’s environmental policies, procedures and guidelines to assist in keeping the center environmentally friendly, you can contact the EEOH or visit the [EEOH website](#).

Hubscher, an Analytical Services Inc. employee, supports the Office of Strategic Analysis & Communications.

NASA Continues Preparation for SLS Engine Testing at Stennis

Think about negotiating an intricate maze, and you begin to appreciate the challenge of designing and fabricating test stand piping for NASA's RS-25 rocket engine.

NASA is meeting that challenge at its Stennis Space Center, where liquid oxygen (LOX), liquid hydrogen and related piping are being produced for RS-25 engine testing on the A-1 test stand. Testing of the core-stage engine for NASA's new Space Launch System (SLS) is scheduled to begin next spring. The SLS is being developed to carry humans deeper into space than ever before.

"This is a big undertaking," said Robert Ek, systems engineer for the RS-25 test project at Stennis. "These are massive lines, weighing hundreds of pounds, and they have to be threaded through a great deal of other stand equipment and structure needed for testing. It's a real challenge."

NASA engineers now are conducting gimbals, or pivot, testing on a J-2X engine on the A-1 stand, but that hot-fire series is scheduled to end in early September. Stand equipment then must be modified to meet RS-25 rocket engine drawing and specification requirements. A new thrust frame adapter already has been fabricated for installation on the stand this fall. Fabrication of the new piping system is underway.

Design of the piping was an involved process that required collecting a lot of information about the RS-25 engine and its performance specifications. Even though RS-25 engines were used as space shuttle main engines, some modifications will be made before testing begins.

"Even with the RS-25 engine's flawless performance on all 135 space shuttle missions, a different rocket like SLS has new environmental and thrust conditions, and therefore, different test considerations," said Mike Kynard, SLS Liquid Engines program manager at NASA's Marshall Space Flight Center. "Anytime we make changes to an engine, or to environmental conditions in which it will run, we'll need to put it through a full set of tests. What we typically do in the rocket engine industry is run things twice as long as we plan to use them in flight to ensure the robustness of the design. We run it at different conditions to make



A welder at NASA's Stennis Space Center works on a portion of piping to be installed on the A-1 test stand for RS-25 rocket engine testing. NASA is scheduled to begin testing RS-25 engines in 2014 for use on the Space Launch System. (NASA/Stennis)

sure we've covered the full range of the design."

Engineers had to take into account new engine performance factors to determine such things as the flow rate of cryogenic fuels needed in the lines and the pressures under which they must operate. In terms of simple geometry, they also had to make sure piping connections were located properly and identify how and where to install supports to hold the piping in place.

"Negotiating a maze is a good analogy," Ek said. "There was a lot of ingenuity and working together to make sure good decisions were made. The design engineering team, supported by both operations and systems engineering, did a great job in finding answers along the way."

The RS-25 testing project was accelerated by a few months, shortening the time for preparation work on the A-1 test stand. The piping now being fabricated by Jacobs Technology crews at Stennis is expected to be completed and installed on the stand by the end of the year.

This article was written by several writers from NASA's Stennis Space Center's Office of Communications.

Jody Singer Updates the National Space Club on Flight Programs and Partnerships



Jody Singer, manager of the Flight Programs and Partnerships Office at NASA's Marshall Space Flight Center, spoke at the National Space Club meeting Aug. 22 at the Jackson Center. Singer gave updates on human exploration, flight mission programs and projects, and International Space Station hardware integration and operations. The Flight Programs and Partnerships Office also is tasked with creating and maintaining partnerships with other government agencies, academia and industry. Singer praised the space community for helping build these partnerships: "We have so much knowledge and skill in the North Alabama area, and collaboration between all of us is vital." (Naheerah King/Huntsville Space Club)

Innovation Through Collaboration: Marshall to Host Innovation & Technology Day Sept. 12

By Bill Hubscher

It takes a team to guide the future of space exploration -- no one person can do it alone. The Marshall Space Flight Center will recognize the importance of collaboration during the annual Innovation & Technology Day Expo on Sept. 12.

The event, open to badged employees of Marshall and Redstone Arsenal, is a daylong expo hosted in Activities Building 4316 showcasing the pioneering technology and developments by various groups across the Marshall Center. The event provides a "show-and-tell" opportunity for the NASA and Redstone Arsenal workforce to learn about -- and potentially benefit from -- another organization's work.

"As the agency has helped drive innovation and advances in the aerospace industry for more than 50 years, it has always been a collaborative team effort," said [Marshall Center Chief Technologist Dr. Andrew Keys](#). "This event is a unique opportunity for the many different teams at Marshall to get a close-up view of each other's work and explore new possibilities for working together and advancing our common goals."



The event is hosted by Marshall's Office of the Chief Information Officer, Office of Strategic Analysis & Communications, and Office of the Chief Technologist.

The expo will feature live demonstrations and hands-on exhibits of the center's technical capabilities and expertise. NASA employees who are unable to attend are invited to watch Marshall Television's live coverage on [DesktopTV](#). The Michoud Assembly Facility, managed by Marshall, also will have exhibit booths displaying its role in NASA's mission and the advances in manufacturing technology it is helping to develop in New Orleans.

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NASA's Chief Knowledge Officer to Host Two 'Masters with Masters' Forums at Marshall

By Kenneth Kesner

Two "Masters with Masters" forums will be presented Sept. 5 at the Marshall Space Flight Center by NASA Chief Knowledge Officer Dr. Edward Hoffman in partnership with Marshall Chief Knowledge Officer Dr. Dale Thomas and NASA TV.

From 9 to 10 a.m., Hoffman will host "Constellation and Return to Flight" with Thomas and Dr. Helen McConnaughey, manager of the Spacecraft and Vehicle Systems Department in the Engineering Directorate at Marshall.

From 10:30 to 11:30 a.m., the topic will be "Russian/International Space Station Integration and Avionics," and Hoffman's guests will be David Mobley and Jerry Clubb. Mobley, now an aerospace consultant, retired from NASA and the Marshall Center after a more than 36-year career that included serving as the agency's chief engineer. Clubb, who also retired after a long NASA career, worked with the Russians on space station software integration.

The Masters with Masters Series reunites colleagues who worked on a challenging program or project for an on-stage interview hosted by Hoffman. No presentations or charts are used during the forums, which are intended to be a personal exchange and sharing of stories between the interviewees. The programs are an opportunity to capture some of the compelling stories, experiences and lessons learned at the center, and to share knowledge on topics, challenges and issues important to NASA and Marshall. Seating for about 40 will be available for the programs in Marshall's NASA TV Studio in the north end of



Dr. Edward Hoffman (NASA)

Building 4207. In-studio attendance is encouraged and the audience is invited to ask questions at the forums, which will be carried live on Center-wide TV, streamed live on [Desktop TV](#) and later shared on the NASA Chief Knowledge Officer/NASA Academy Web pages, other NASA websites and social media.

For more information, contact Jennifer Stevens at jennifer.s.stevens@nasa.gov or 256-544-5004, or Susan Snyder at susan.snyder-1@nasa.gov or (301) 837-3918.

For TV studio seating arrangements, contact Stevens at jennifer.s.stevens@nasa.gov or 254-544-5004.

Kesner, an Analytical Services Inc. employee, supports the Office of Strategic Analysis & Communications.

Innovation & Technology Day *Continued from page 5*

The activities run from 10 a.m. until 3 p.m. Lunch vendors will be on-site and buses to certain buildings will provide local transportation to and from the expo. For the latest information, including bus schedules, visit ExplorNet or view the 2013 Innovation & Technology Mobile App by scanning the QR code with a smartphone.

The code and the application to which it leads were created by the Office of the Chief Information Officer

as a sample of what the office can offer and the kinds of innovations attendees will discover at the expo.



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Major James Webb Telescope Component Arrives at Marshall and on NASA-TV

A major component of the [James Webb Space Telescope](#) arrived at the Marshall Space Flight Center on Aug. 22. The arrival of the “backplane” of NASA’s next great space observatory is featured in the latest edition of “[This Week @NASA](#),” a weekly video segment broadcast on NASA-TV and posted online.

The hardware, which arrived on a C-5 cargo plane from ATK in Promontory, Utah, will be tested in the Marshall Center’s X-Ray and Cryogenic Facility. You can watch this edition of This Week @NASA at the [NASA-TV YouTube channel](#).



Obituaries

Sylvia Elizabeth Balch Thomas, 90, of Huntsville, died Aug. 16. She retired from the Marshall Center in 1999 as a personnel management specialist. She is survived by her husband, Ronold Bernard Thomas.

Harlan Duane Burke, 83, of Plain, Miss., died Aug. 16. He retired from the Marshall Center in 1985 as an aerospace engineer. He is survived by his wife, Dorothy Finch Burke.

Edis Lorell Cottles Richardson, 83, of Huntsville, died Aug. 17. She retired from the Marshall Center in 1994 as a secretary. She is survived by her husband, Reeder Richardson.

Robert James Vanderzyl, 82, of Huntsville, died Aug. 21. He retired from the Marshall Center in 1994 as a computer engineer. He is survived by his wife, Cynthia Vanderzyl.