National Aeronautics and Space Administration

Liquid Propulsion Technology and Development

Affordable Development for the Next Decade

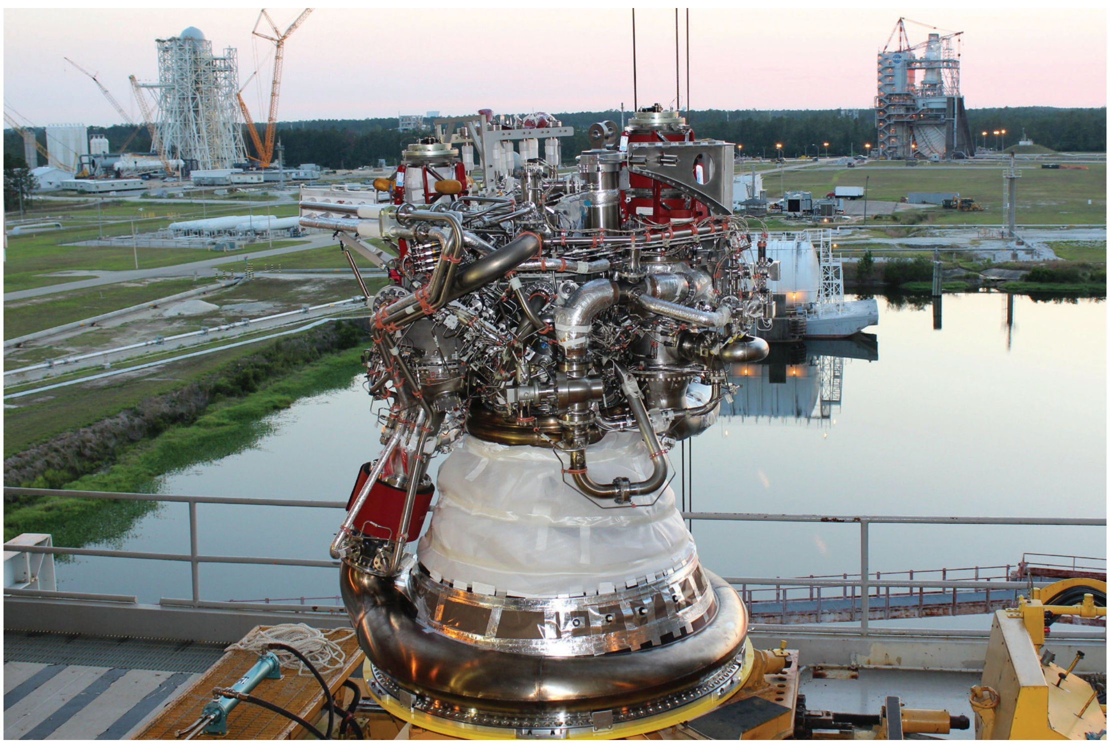
Development of new launch and in-space liquid propulsion solutions for the exploration needs of the future hinges on purposefully maturing design approaches to provide affordable development paths. Marshall draws on decades of experience with almost every propulsion system developed, both small and large, and is applying innovative approaches such as additive manufacturing to shorten development cycles, improve integration of propulsion systems with vehicles, and validate new technologies prior to production.

Marshall provides affordable, comprehensive liquid propulsion capabilities that meet the needs of NASA, Department of Defense, and private industry — from conceptual design and development and testing to mission support. Marshall's unique capability to design, fabricate, test, and analyze liquid propulsion systems on site allows customers to optimize resources, consolidate project management, and reduce risk.

The Center's expertise ranges from small pressure-fed to large, complex pump-fed rocket engines that support liquid propulsion requirements for Earth-to-orbit, beyond-Earth orbit, and in-space missions. Marshall's technical expertise and experience are matched with the Center facilities, laboratories, and equipment needed for any aspect of liquid propulsion system development.

At-A-Glance

Affordable development of liquid propulsion systems is critical to remaining nationally competitive and to advancing exploration goals. Cost-effective propulsion development preserves a larger portion of available budgets to accomplish scientific and exploration goals. Marshall Space Flight Center leverages its significant experience, broad discipline expertise, and comprehensive facilities to ensure reliable and affordable liquid propulsion solutions to meet Agency and national priorities.



Marshall continues to improve performance of the J-2X engine to meet future mission needs.

Since development of operational space transportation systems and architectures represents long-term, often generational, investments of public resources, Marshall's management, oversight, and insight roles for complex propulsion system development and operations represent critical safeguards and stewardship of these investments. Use of advanced manufacturing methods, integrated design/development strategies, and acceptance of risks on early development hardware drive down costs and improve system performance and reliability.

Drawing on History To Design the Future

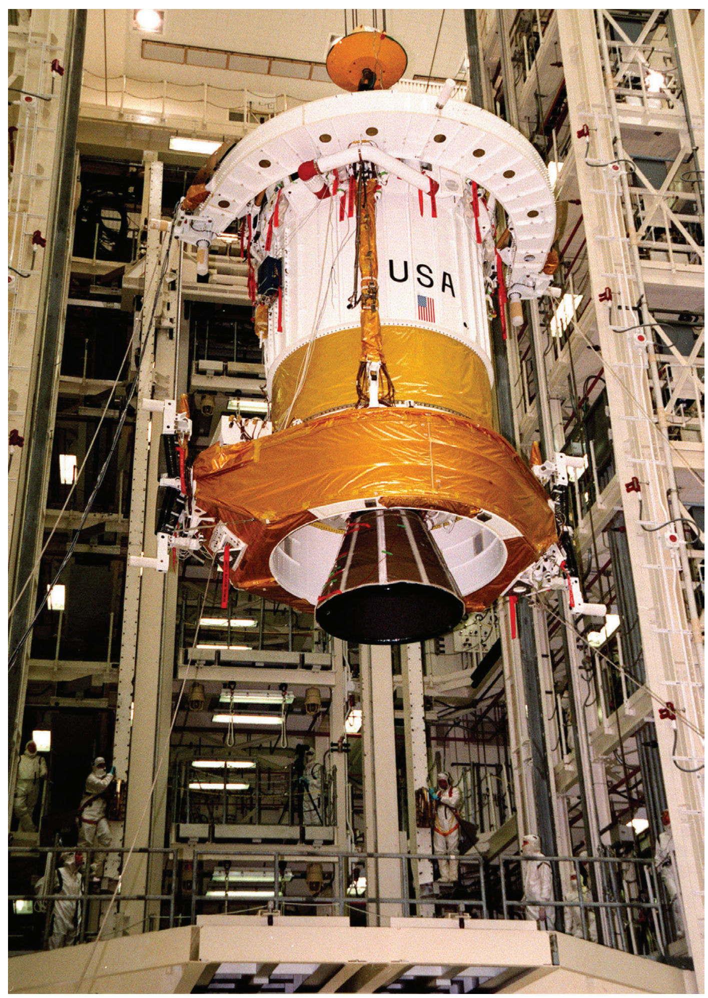
For over five decades, Marshall's scientists and engineers have designed, developed, integrated, and sustained liquid propulsion systems that have set the pace for historic advancements in space exploration. Building on the past, Marshall inspires confidence in future launch vehicles, including the heavy-lift Space Launch System (SLS) now under development. Leveraging Marshall's success in previous propulsion system development reduces schedule and cost requirements in propulsion development for a range of future applications, including SLS and in-space mission needs.

Apollo Program — Marshall developed Saturn's F-1 engines from testing to flight and the second stage J-2 engines from earliest concept development to flight. The F-1, to this day the most powerful single-nozzle liquid-fueled engine ever built, is being leveraged for SLS Advanced Booster concept development. Using state-of-the-art techniques such as structured light scanning and 3-D printing to translate an existing F-1 engine into a full-fidelity CAD model, Marshall's liquid propulsion experts are examining ways to build on the significant investment of the Apollo Program to reduce costs and improve performance of the SLS.

Space Shuttle — The Center led the design of the Space Shuttle Main Engine (RS-25), which achieved a demonstrated reliability exceeding 0.9996 over 135 missions. Through 30 years of block upgrades and design refinements, the RS-25 continued to incorporate technological advances and improved manufacturing techniques to increase affordability, reliability, and operability. That process of continual improvement continues to pay off today, as the RS-25 is being prepared by Marshall for use in the SLS core stage.

Chandra X-ray Observatory — The Marshall-managed Inertial Upper Stage (IUS) system was used in launching a number of flagship-class science missions during the shuttle era, including Magellan, Galileo, and Ulysses. Marshall led the effort to determine how to boost the Chandra X-ray Observatory — at the time one of the largest and heaviest payloads ever flown — from a shuttle cargo bay to an orbit 87,000 miles above Earth. The IUS was only capable of placing Chandra in a 37,000-mile orbit, so Marshall was tasked with designing an in-space propulsion system to reach the additional 50,000 miles. The resulting dual-mode liquid propulsion system worked in tandem with the IUS to reach the required orbit, delivering groundbreaking data that revolutionized X-ray astronomy. Marshall continues to develop in-space propulsion systems for future science and exploration missions, collaborating with other NASA centers, industry partners, and government agencies.

Constellation Program — In another example of drawing from the lessons of the Saturn rockets, Marshall engineers undertook the design, development, and testing to upgrade the Saturn upper stage J-2 engine to the J-2X engine for use on the upper stages of both planned Ares launch vehicles. Improvements in manufacturing and materials technologies, combined with decades of additional lessons learned about liquid propulsion systems, have been leveraged to design a J-2X engine that will be more reliable and more affordable than its Apollo precursor. With the change from the Constellation Program to SLS, the Marshall SLS Liquid Engines Office continues testing the J-2X at Stennis Space Center as a candidate for powering an SLS Upper Stage.



Marshall's improvements to Chandra's IUS provided the performance boost necessary for revolutionary scientific returns.

	Launch Propulsion Systems	High-Performance Departure Stages	Nuclear Cryogenic Propulsion Stage	High-Performance Descent/ Ascent Propulsion	Robotic, SM, Sample Return, Other Transportation	Satellite, Spacecraft, Small Satellite Systems
Liquid Engine Design	■	■	■	■		
Main Propulsion Systems	■	■	■	■	■	
In-Space Propulsion Systems		■	■	■	■	■
Turbomachinery	■	■	■	■		
Combustion Devices	■	■		■	■	■
Valves, Actuators, and Ducts	■	■	■	■	■	■
Thrust Vector Control	■	■	■	■		
Attitude Control Systems	■	■	■	■	■	■
Health and Status Systems	■	■	■	■	■	■
Instability Analysis	■	■	■		■	
Combusting and Unsteady Flow Fluid Dynamics	■	■	■	■	■	■
Propulsion Systems Integration	■	■	■	■	■	■

Space Launch System — Marshall engineers recently assembled and ignited a cluster of subscale thrusters to verify the SLS propulsion elements before creating a full model mockup. The combined subscale elements simulate the intense conditions of the SLS propulsion system. Marshall fabricated the thruster injectors out of Inconel 625 using state-of-the-art selective laser melting (SLM) processes. These injectors were taken from design through fabrication to the test stand for half the cost and in 15 percent of the time required for traditionally fabricated injectors. Marshall continues to develop these advanced tools and techniques to achieve greater affordability in liquid propulsion system development.

Every Liquid Propulsion Discipline In-House

Marshall's expertise in the area of liquid propulsion covers the entire systems life cycle — from early concept development to detailed analysis and design, through full-scale assembly, testing, operation, and mission support. This end-to-end expertise enables engineers to design with an eye toward manufacturing, operations, and sustaining engineering, which results in more cost efficiency thanks to the Center's unique perspective on the long view of a propulsion system's life cycle.

This expertise encompasses every liquid propulsion discipline from engine and spacecraft systems down to components such as lines, valves, turbomachinery, thrust vector control, injectors, nozzles, chambers, gas generators, and cryogenic fluid management. Identifying cost drivers at the component and subsystem level allows designers to rapidly develop and test improvements, reducing overall development time and cost and ensuring reliability of the final flight hardware. Marshall's co-located cross-discipline team also allows for more rapid design cycles of propulsion systems and subsystems, which also lowers development costs. The high degree of collaboration practiced among the Center's propulsion experts and cross-cutting experts in areas like structures, materials, fluid dynamics, and systems engineering also results in fewer design cycles and revisions, saving cost and schedule.

Comprehensive Facilities for Design, Development, Fabrication, and Testing

Marshall maintains a comprehensive array of facilities that help engineers devise, fabricate, and test liquid propulsion technologies and concepts. These facilities include component manufacturing, performance characterization, and testing, allowing engineers to more quickly move from design to fabrication of test articles and then from the testing and analysis of those articles to design revisions to address any performance issues. This ability to move rapidly through design cycles to arrive at optimized solutions leads to more cost-effective investment of development dollars.

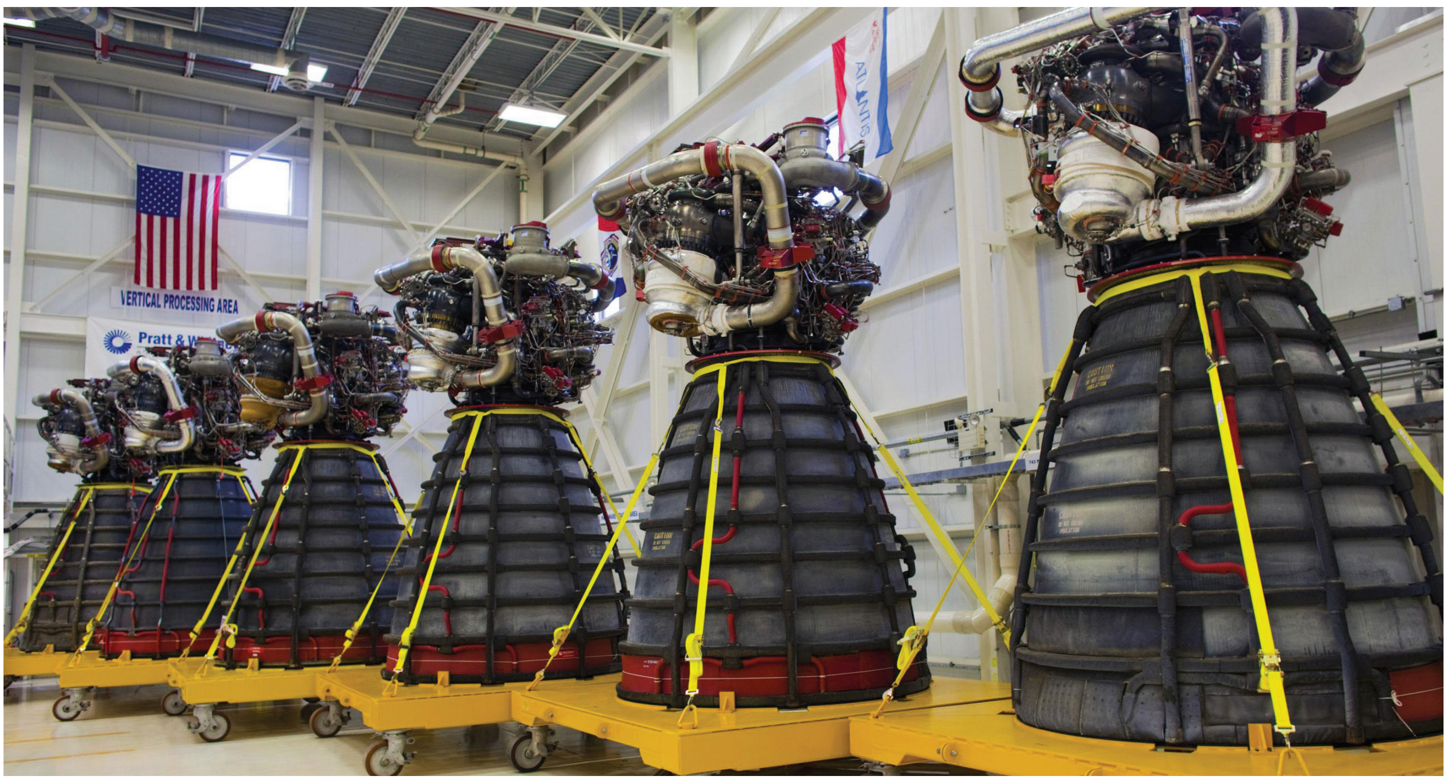
The facilities available to the liquid propulsion engineers at Marshall enable testing of components, subsystems, subscale motors, and full-scale engines under a variety of configurations and conditions. The test engineers in this area have supported many prior NASA programs, including Saturn, space shuttle, and technology development engines such as Fastrac, and are continuing to support development of the SLS propulsion systems design.

The RS-25 Engine: the Evolution of the Highest-Performing Engine Ever Built

The RS-25 engine, most recently seeing service as the Space Shuttle Main Engine (SSME), is the most reliable and highly tested large rocket engine ever built. Throughout the Shuttle Program, Marshall was responsible for the SSME's development, testing, and operation. As industry partners emerged, disappeared, and consolidated over the life of the program, the Center provided a consistency of purpose and design to ensure the engine's unparalleled reliability. During the 30-year space shuttle era, the RS-25 achieved 100 percent flight success with a demonstrated reliability exceeding 99.9 percent. During 135 missions and related engine testing, the RS-25 system accumulated more than 1 million seconds of hot-fire experience.

Improvement of the RS-25 was continuous during the shuttle era. Upgrades were made to the combustion chamber, turbopumps, injectors, and even weld processes to improve the engine's performance and increase its reliability, while simultaneously reducing the required maintenance efforts between missions to lower costs. In addition to the continual efforts to improve upon the RS-25 design, Marshall provided all the necessary sustaining engineering support for the engines and associated propulsion subsystems to the Space Shuttle Program throughout the operational life of the shuttle.

That heritage gave Marshall confidence in selecting available RS-25 engines for the core propulsion of SLS. Under the continued direction of Marshall's SLS Liquid Engines Office, the remaining RS-25 inventory held over from the space shuttle are being prepared to serve as the main propulsion component of the SLS core stage. The RS-25 inventory — the equivalent of 16 engines — represents over $1 billion in assets, thus contributing to SLS affordability. Its proven performance will also contribute to SLS safety and sustainability.



Marshall will leverage $1 billion in existing RS-25 assets to reduce costs for SLS core stage propulsion.

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