National Aeronautics and Space Administration

Thermal and Fluid Systems

From State of the Art to Standard Practice

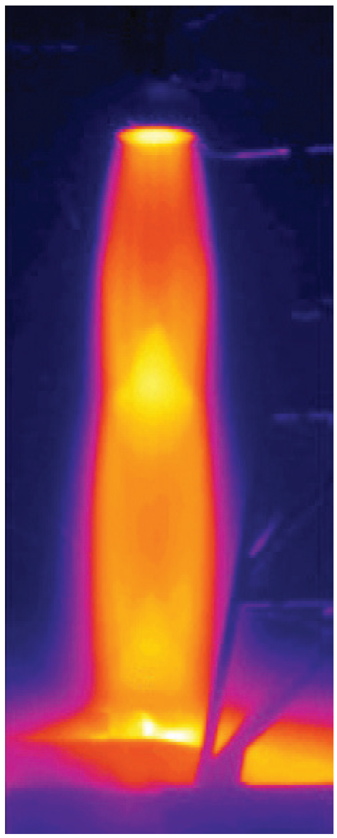
The development of launch vehicles, spacecraft, and associated payloads requires the capability to accomplish fluid dynamics and thermal design, analysis, and test activities to ensure the timely development of reliable systems and components that deliver the required performance. Marshall advances the state of the art in these disciplines, developing tools and analysis techniques that are adopted as educational and industrial standards.

Marshall's thermal and fluid dynamics systems capabilities are an extensive collection of expertise, methods, tools, and facilities used to ensure that launch vehicles and space systems are designed and built to reliably withstand the demanding environments in which they must operate. Marshall provides a targeted, sophisticated approach to every project and has created a national reputation and demand for its expertise and unique custom-developed tools.

Although a separate discipline, fluid dynamics is often an important aspect of thermal analysis, and the two disciplines often intersect.

Thermal Analysis: Every launch vehicle and spacecraft hardware system operates in extreme, complex, and interrelated thermal environments that must be understood and accounted for in the system's design to control and maintain all elements of the launch vehicle space system within its temperature limits in all phases of its mission.

Fluid Dynamics: Fluid flowing through or around a hardware system and/or component creates system-level and local-level structural loads and thermal environments that must be analyzed and designed for. The fluid behavior, loads and environments the system must account for are especially extreme and complex when high fluid velocities are involved.



Infrared analysis of engine tests verifies that designs will meet performance requirements.

At-A-Glance

From decades of experience on launch vehicles, space systems, and complex scientific observatories, Marshall Space Flight Center's thermal and fluid analysis engineers have developed an extensive suite of customized design tools and the expertise to quickly apply the right tools to find solutions that meet performance needs. Coupled with deep interdisciplinary reachback and unique test capabilities, Marshall's thermal and fluid capabilities are critical to enabling smart design.

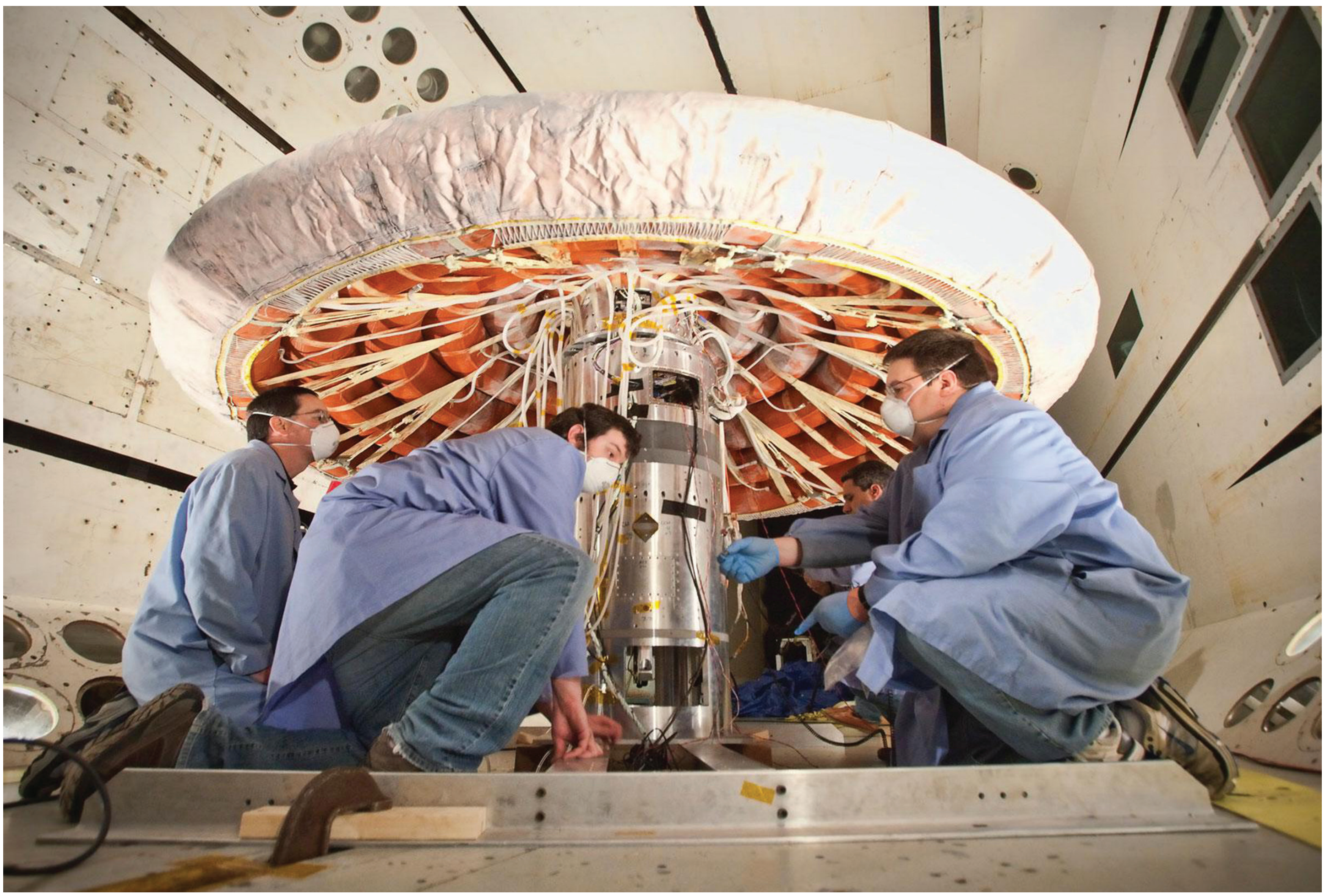
Discipline Expertise and Broad Mission Experience

From the simplest payloads to the most complex spacecraft and launch vehicle systems, Marshall provides a full spectrum of capabilities for thermal and fluid dynamics engineering disciplines. Center capabilities support propulsion systems, launch vehicles, and upper stages; spacecraft and spacecraft systems; the International Space Station; advanced exploration systems; the Space Technology Program; and various external collaborations. Our legacy team offers 30 years of experience with heritage hardware and human spaceflight and has been sought out by commercial space partners for consultation and solutions.

A recent success of Marshall's unique analysis methods came about on the Orion Launch Abort System Attitude Control Motor (ACM) where a carbon fiber rope assembly gap closeout thermal barrier system was recommended and used. The analysis approach for this system, derived by Marshall, enabled quick functional assessment and implementation into the ACM hardware, ensuring that program milestones were achieved on schedule. Marshall's team offers not only analysis but also deep experience with the development, selection, and application of analysis tools needed during development.

Turning Unique Tools into Industry Standards

Marshall has a diverse array of software design and analysis tools and test facilities to support thermal and fluid dynamics capabilities. Several of the unique thermal and fluid dynamics tools that have originated from Marshall have been embraced by the private sector and incorporated into educational materials as industry standards.



Engineers at Langley used Marshall's GFSSP software to predict pressure and flow rates on the IRVE-3 experiment before flight.

Generalized Fluid System Simulation Program (GFSSP)

The GFSSP code is a finite volume-based thermo-fluid system analysis tool, with emphasis on thermodynamics. It was developed at Marshall in 1996 to analyze propulsion system and internal flow of turbo pumps for the Fastrac engine. Its design is user-friendly, with an intuitive graphical user interface, robust solver, and extensive training materials and support.

GFSSP's capability has been regularly enhanced to improve its modeling capability and user interface, having gone through six incarnations with multiple upgrades. The code can be used in any kind of flow circuit to perform steady state or transient analysis of pressure, flow rate, and temperature distribution.

It received the NASA Software of the Year award in 2001 and currently has several hundred users across the Agency, Air Force, Navy, Army and private industry. An educational version of the code is being used in several U.S. universities for teaching thermal design to the next generation of engineers.

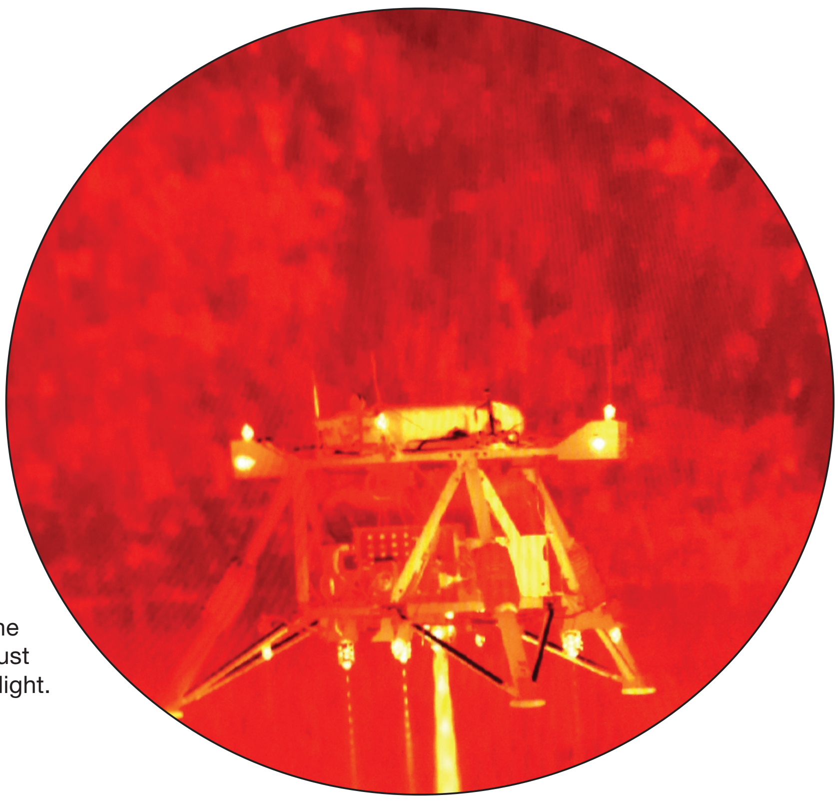
GFSSP was used by Langley Research Center to design the inflation system of Inflatable Reentry Vehicle Experiment (IRVE3). The purpose of this technology is to protect a spacecraft when entering a planet's atmosphere or returning here to Earth. IRVE3 successfully flew in July 2012. GFSSP prediction of pressure and flow rate in the inflation system during flight matched very well with the flight data.

Infrared Thermography

The Marshall thermal analysis team specializes in infrared thermography, the acquisition and analysis of thermal information from no-contact thermal imaging devices. Of particular note, the team specializes in calibrated high-temperature infrared thermography through the use of sophisticated cameras.

The specialty consists of a sophisticated network of cameras, data computers, data networks, remote triggering, and IRIG timing and serves a variety of customers. In environments and tests where direct contact is not possible — or is even dangerous — or results are not measurable by other methods, infrared imaging can safely "see" results that other instruments cannot. The cameras can capture plume structure, debris fallout, or temperature differentiations that provide valuable test data that could prevent potential problems.

Collaborations and customers include the Space Shuttle Program, International Space Station, Constellation's Altair lunar lander and Ares launch vehicle, J-2X engine development, and SLS materials analysis. These improved thermal and fluid analysis tools are also incorporated into existing test facilities at Marshall, such as the X-ray and Cryogenic Facility and the Hot Gas Facility.



Infrared thermography of the Mighty Eagle lander shows thrust plume structure during a test flight.

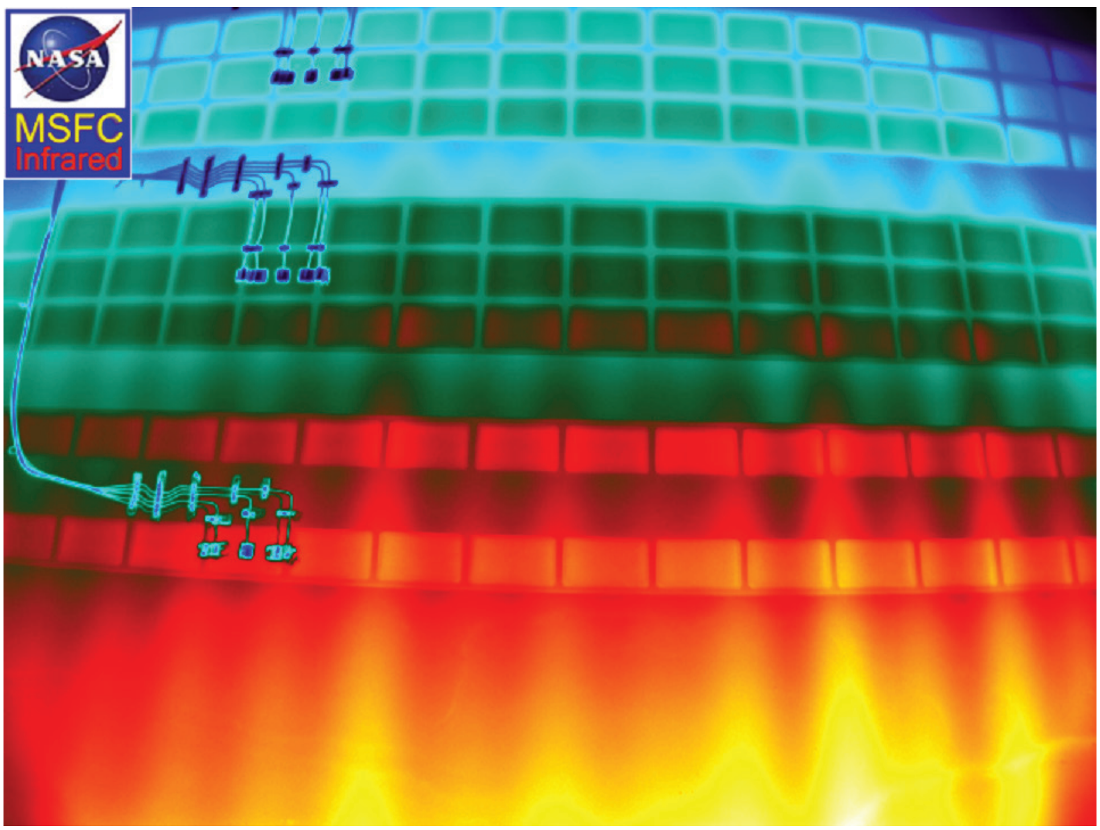
Improving Data Capture for Engine Testing Capabilities

The SLS upper stage J-2X engine was tested at Stennis Space Center's A2 test stand from February 2013 to April 2013, using a regenerative-cooled nozzle extension that further expands the plume for higher specific impulse.

The analysis team requested infrared thermography to validate the predicted temperatures. Thermocouples installed on the nozzle extension provided point temperature measurements, but it was impossible to cover the entire assembly due to the high cost.

A team of Marshall and Stennis engineers and technicians designed, constructed and installed two new clamshell infrared camera windows and housing to measure nozzle temperatures. The cameras were able to determine that the test stand diffuser coolant water and purge gas were preventing the extension from reaching the designed temperature profile. The camera provided data to reduce the coolant water and purge to obtain a more "flight-like" vacuum environment for the nozzle extension. The cameras also detected a hot streak that was not detected with the thermocouple instrumentation.

This methodology is being incorporated in other similar testing environments, providing a data capture ability that has always been desired but has not been available until now.



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