National Aeronautics and
Space Administration

Materials Diagnostics and Fracture/Failure Analysis

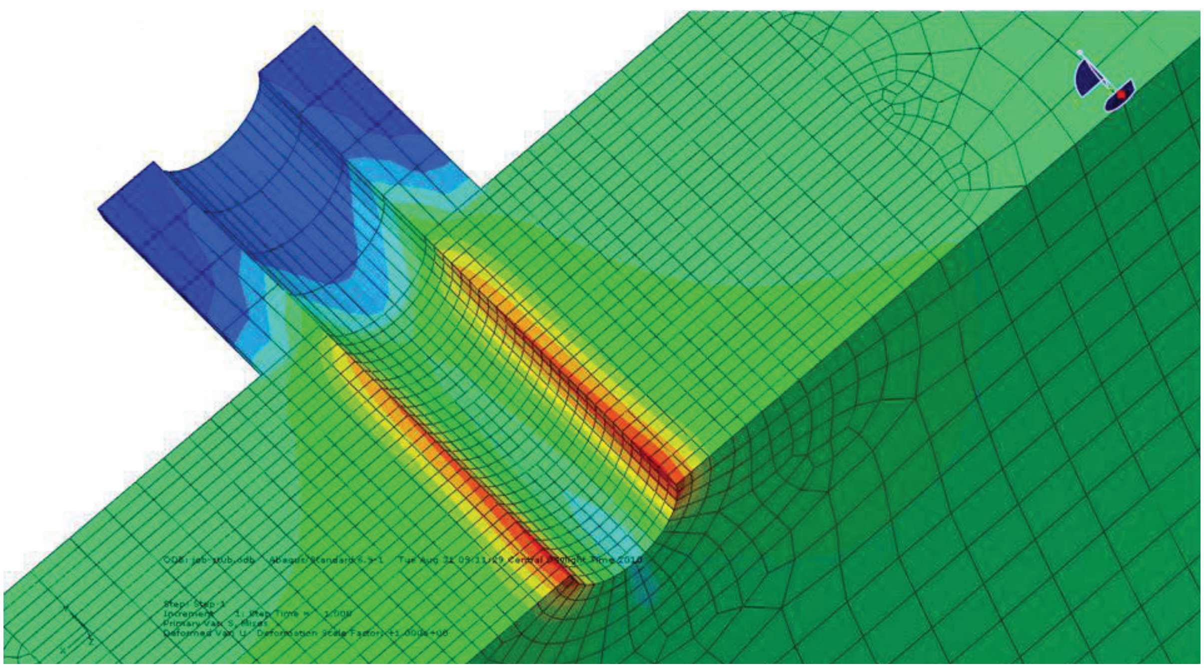
Ensuring Mission Safety and Advancing Space System Manufacturing

Preparing for missions in space requires continually incorporating new materials and processes that enable delivery of cutting-edge design solutions and yet still meet stringent safety requirements for crewed systems. Marshall quickly and thoroughly identifies materials performance and failure issues, advancing the state-of-the-art in space system manufacturing and testing and leading to safer space solutions to meet Agency needs.

Marshall's materials diagnostics, damage tolerance, and failure analysis capabilities ensure crew safety and mission success throughout the service life of spaceflight vehicles, habitation modules, and propulsion systems. This extends down to the component and subcomponent level, including core materials, coatings, and hardware, as well as the manufacturing processes to deliver them. The Center has a proven track record as a leader in safely, routinely delivering sound, reliable launch vehicles, spacecraft, and hardware — from manufacturing to low-Earth orbit and beyond.

At-A-Glance

Space applications require continual incorporation of new materials and processes to identify the lowest cost and lowest mass solutions. Advancing design while meeting safety requirements requires an expert team that can identify material performance and failure issues quickly and comprehensively. By continually advancing the state-of-the-art in materials diagnostics and failure analysis, Marshall Space Flight Center is helping to evolve and improve space system manufacturing leading to safer, more affordable solutions.



Marshall's state-of-the-art diagnostics ensure safe, affordable design solutions.

Keen Analysis, Expert Diagnostics

Historically founded in quality assurance during the Apollo Program and continuously evolving with advancing technology, Marshall's materials diagnostics, damage tolerance, and failure analysis capabilities are vital to NASA's mission. Marshall experts pursue an interconnected series of specialties in these fields — adding up to a national resource for this complex and critical activity. Marshall has unique expertise and in-house knowledge to correlate advanced fracture analysis with hardware tests, as well as a full complement of non-destructive evaluation (NDE) techniques, technologies, and test facilities.

Marshall has extensive experience in conducting damage tolerance testing (fatigue and fracture testing) of critical NASA and industry hardware and processes, proving hardware and materials for space shuttle and supporting development of the latest next-generation vehicles and space systems. The Center experts in crack growth analysis in propulsion systems and large-scale structures worked closely with Boeing to conduct fracture testing on friction stir welds for the Space Launch System (SLS) Core Stage, helped detect the cause of cracked stringers on the STS-133 external tank, and aided Orbital and Aerojet in investigating manufacturing defects and stress corrosion cracking in AJ26 heritage engines.

The Center frequently is called upon by Agency and industry partners to perform custom NDE inspections of hardware and vehicles, including test articles and elements for SLS, next-generation Cryogenic Propellant Storage and Transfer, and International Space Station (ISS) hardware. Marshall also partners with industry, supporting NDE evaluations for ATK, Aerojet Rocketdyne, Blue Origin, Boeing, Dynetics, Lockheed Martin, and other industry partners.

Marshall is a recognized resource for anomaly resolution and failure analysis at any scale, supporting many successful investigations, including examination of Solar Alpha Rotary Joint (SARJ) bearing failure on the ISS and the crash investigation of TWA Flight 800 in 1996.

Together, the damage tolerance, NDE, and failure analysis teams perform a variety of vital root-cause assessment tasks. Key assessments have included:

- Failure analysis of leading-edge composites after the Columbia accident
- Computation of acceptable disbond sizes for a cryogenic tank common bulkhead honeycomb sandwich structure
- Analysis of Space Shuttle External Tank spray-on foam insulation (SOFI) failure mechanisms and debris liberation
- Failure analysis of Apache, Blackhawk, Chinook, and Observation helicopter parts
- Development of phased array ultrasonic testing for friction stir welding and friction stir plug welding
- Investigation of high-cycle fatigue and hydrogen embrittlement effects of Space Shuttle Main Engine (SSME) high-pressure fuel turbopump turbine blades
- Failure analysis and test evaluation of debris liberation estimates supporting STS-126 Shuttle Main Propulsion System flow control valve fracture

Expert Analysis To Ensure Safety and Mission Success

Marshall crack growth analysis experts leverage state-of-the-art technologies, advanced investigative methods, and proven tools and testing standards to develop and implement thorough, precise assessments to mitigate risk due to damage and defects in manufacturing and assembly and throughout the hardware life cycle. They identify defects in materials, discover how defects are formed, and determine how much damage each material can withstand — whether sustained during a launch or in-flight anomaly or accumulated over the course of the life cycle.

To ensure that flight hardware, payloads, and launch vehicles are strong enough to survive the rigors of launch and spaceflight, Marshall analyzes metals and composites to understand each material's ability to withstand the loads and conditions encountered during mission life. Center experts co-chair the Agency's Fracture Control Methodology Panel to ensure uniformity of fracture control standards and requirements across NASA. They also chair the Fracture Control Board at Marshall.

When it becomes necessary to examine intricate, complex pieces of hardware without pulling them apart to see how they survive testing or use, the Non-Destructive Evaluation team conducts in-house analysis of laboratory results for hardware acceptability and flight rationale.

The Failure Analysis team uses tools and techniques to assess and diagnose failures in hardware, coatings, processes, and products, reducing the likelihood of further project/mission setbacks or delays.

World-Class Sites of Innovation

Mechanical Test Facility

Enabling engineers to conduct standard and nonstandard mechanical tests, from elevated to cryogenic temperatures, the Mechanical Test Facility is home to a wide range of customized tests to evaluate stress and fracture issues — including simulated service loads in simulated space environments. Standard tests meet all government and industry specifications.

Hydrogen Test Facility

The Hydrogen Test Facility is a unique national resource, featuring eight structurally reinforced test cells that enable an extensive, customizable range of stress-, pressure-, and temperature-based hydrogen tests. This facility was the first in the world to run high-pressure cryogenic permeability tests in liquid hydrogen at pressures up to 300 psi.

Materials Diagnostics and Failure Analysis Facilities

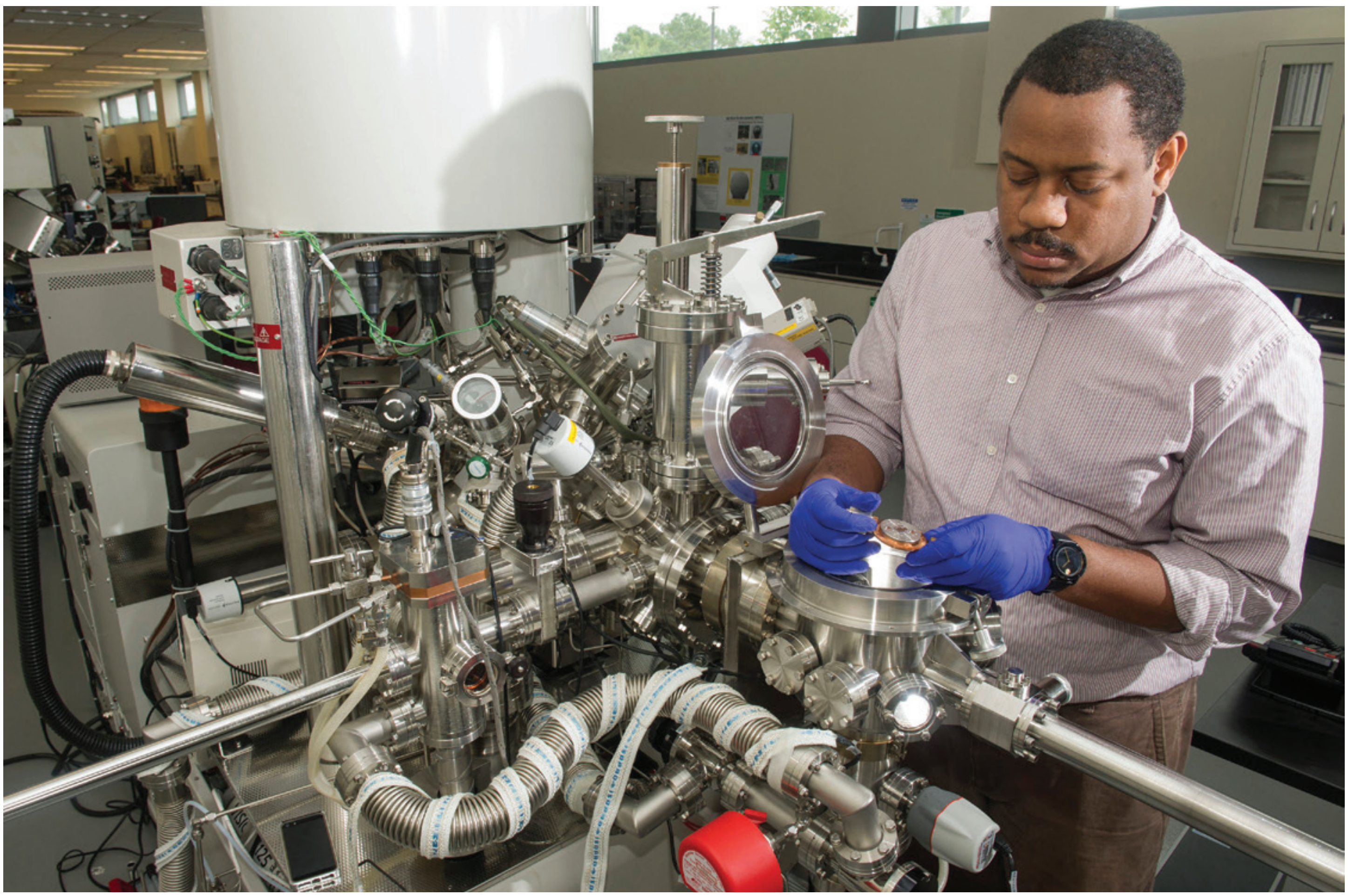
Highly skilled, highly trained Marshall engineers investigate the underlying, contributing causes of failures in order to minimize operational risk and optimize system reliability. Marshall's Materials Diagnostics and Failure Analysis Facilities maintain a suite of optical, stereo, scanning and transmission microscopes suitable for analyzing metallic, composite, ceramic, biological, and geological samples.

Surface Analysis/Microscale Material Characterization Facilities

Low-voltage/high-resolution electron microscopy, X-ray photoelectron spectroscopy, and secondary ion mass spectroscopy are used by Marshall researchers in the Surface Analysis/Microscale Material Characterization Facilities to perform detailed analysis of thin films and submicroscopic deposits. They also provide detailed data interpretation for individual materials applications.

Non-Destructive Evaluation Facilities

Marshall's Non-Destructive Evaluation Facilities provide critical NDE development, analysis, and inspection capabilities for large-scale structures, propulsion systems, and flight articles using standard and specialized methods and equipment — from radiography, eddy current technology, and magnetic particle inspection methods to phased-array ultrasonics, computer tomography, laser shearography, terahertz, thermography, and microwave methods.



X-ray analysis of materials is one of many methods used at Marshall to reduce risk.

Out of the Past, into the Future

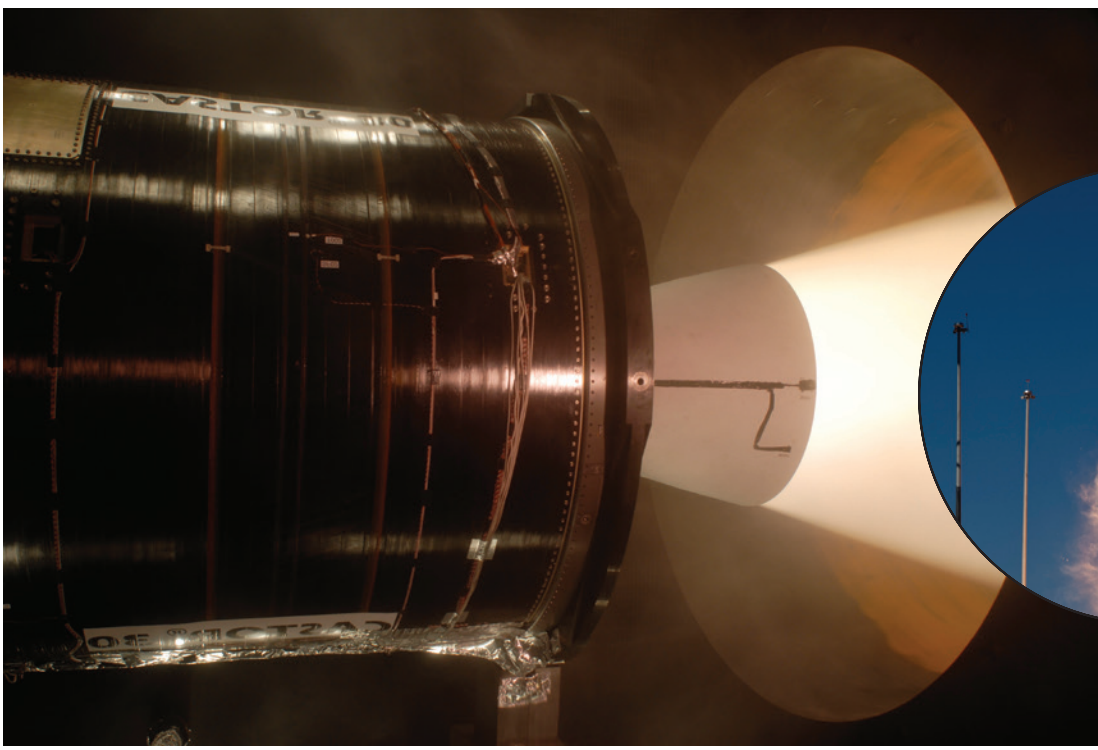
Marshall materials engineers provided critical assistance to Orbital Sciences Corp. and Aerojet in the assessment of structural material capability for the AJ26 liquid rocket engines used on the modern Antares launch vehicle.

The AJ26 engines are slightly modified Russian NK-33 engines built in the early 1970s. Because the engines are heritage Russian hardware, details of the material capabilities are not available, and heritage Russian production processes no longer can be readily replicated — especially for the welds on the engine ducts.

To meet this materials diagnostics challenge, the Marshall team had to determine innovative ways to dissect and test extremely limited amounts of sacrificial engine hardware to determine its capabilities in the presence of stress corrosion cracks.

Given the highly complicated, curved surfaces of the engine hardware, the team devised unique test-specimen designs, test fixturing, test measurements, and nonlinear analysis techniques.

Using Marshall's state-of-the-art facilities and in-house expertise, the team successfully determined the full range of capability of the welded engine material. Now, Orbital and Aerojet are putting the results of that comprehensive testing to practical use — ensuring continued successful operation of the Antares launch vehicle.



Marshall's expert assessment of AJ26 engines helped keep Antares on schedule.

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George C. Marshall Space Flight Center
Huntsville, AL 35812
www.nasa.gov/marshall

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