National Aeronautics and Space Administration

Structural System Design and Analysis

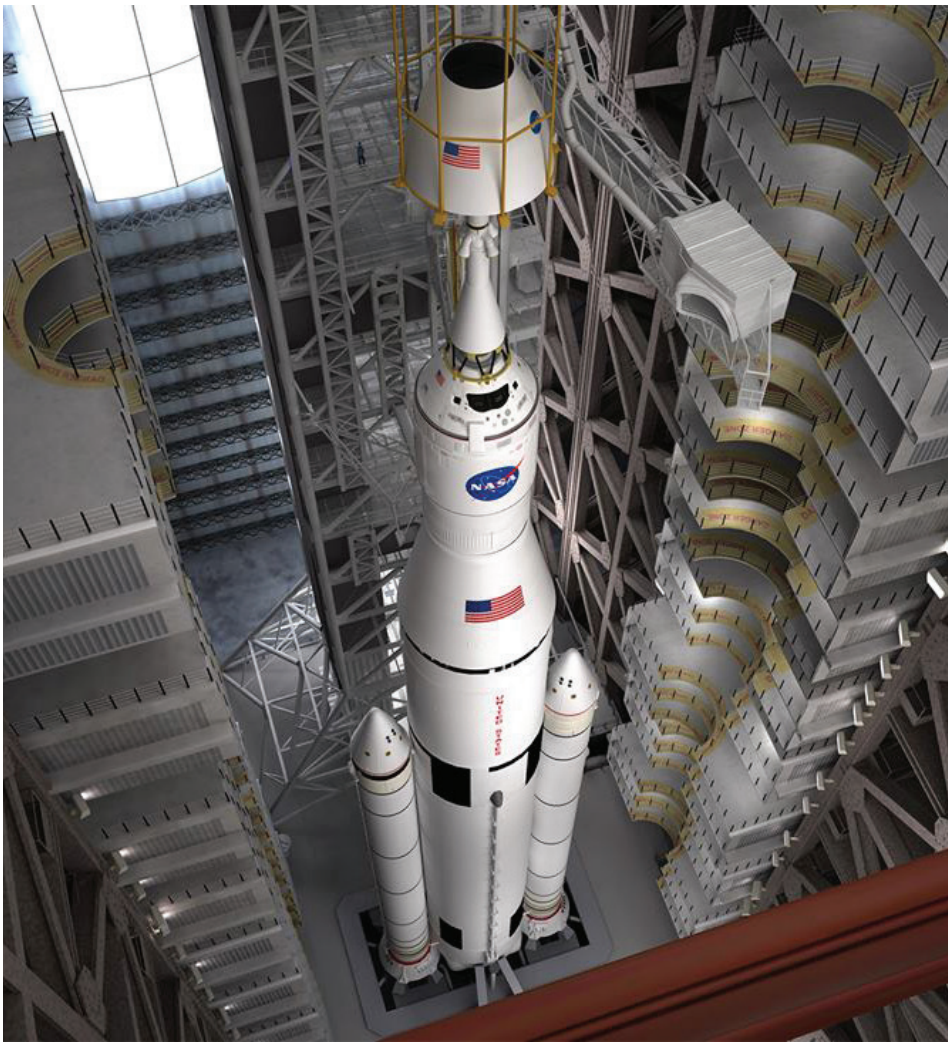
Minimizing Mass, Ensuring Integrity

From concept development through mission execution, Marshall Space Flight Center delivers customized, affordable, and optimized structural systems design and analysis solutions, ensuring the physical integrity of spacecraft and launch vehicles in all applicable environments.

The structure of any hardware-based system is its backbone, supporting components in all expected natural and induced operating environments. Marshall's Structural Systems Design and Analysis (SSDA) capability uses a broad suite of methods and tools to ensure the physical integrity of prototype, development, ground, and flight hardware systems. From the simplest payloads to the most complex spacecraft and launch vehicle systems, from concept initiation through mission operations, Marshall provides comprehensive SSDA capabilities.

At-A-Glance

Marshall is a leader in the structural design of launch vehicles and in-space staging crucial for future scientific and exploration missions. Collaboratively in the design process, Marshall offers a full spectrum of design and analysis capabilities to provide independent assessment, insight/oversight, or in-house development as needed for missions. State-of-the-art tools and unique facilities serve a diverse customer base across the Agency, as well as partnerships with other government agencies and the aerospace industry.



Advanced modeling tools ensure that structural designs meet requirements for both ground processing and in-space operations.

STS-133 External Tank Insulation

Throughout the life cycle of the Space Shuttle Program, Marshall engineers collaboratively provided design and analysis capabilities and assessments for the individual missions.

On November 5, 2010, launch of Space Shuttle Discovery on STS-133 was scrubbed due to a small hydrogen leak at a ground umbilical connection. Routine visual inspections of the external tank revealed an unusual crack in the sprayed-on foam insulation at the forward end of the intertank. Repairs showed a more serious problem — an underlying aluminum stringer, or structural stiffener, had fractured. An adjacent stringer was similarly fractured, although the foam over it appeared undamaged. Understanding the cause of the fractures and developing a repair concept were required before launch. Marshall, as managing center for the external tank project, coordinated the work with the prime contractor, Lockheed Martin, and other NASA organizations. Marshall brought to bear a wide array of capabilities in material science, structural analysis, and structural testing.

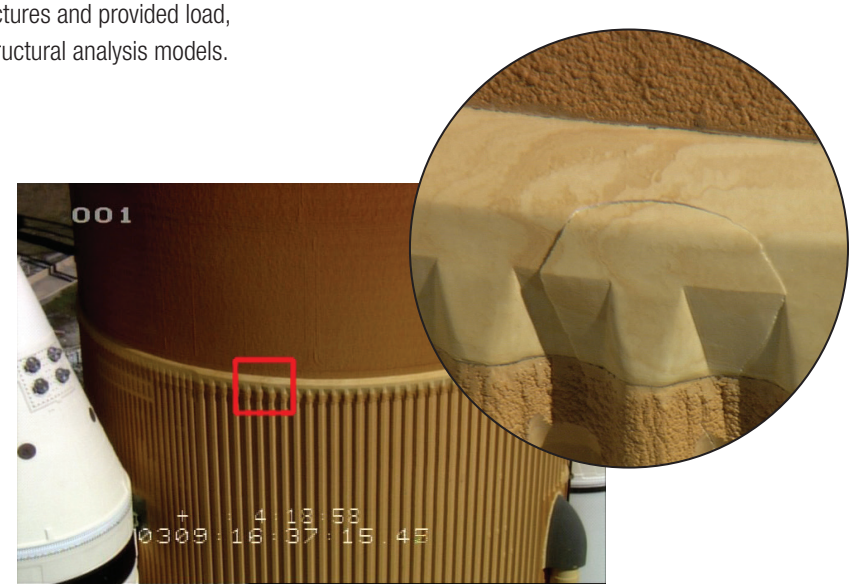
Non-destructive X-ray inspection revealed three more cracked stringers. Forensic analysis of sections removed from the first two cracked stringers revealed no pre-existing cracks or defects and that the stringers fractured in overload with no evidence of fatigue. Testing concluded that the aluminum material satisfied all specifications, including minimum strength and elongation.

Marshall engineers augmented Lockheed Martin in studying the stringers under various temperature and loads and developed a structural test program for static load testing of individual stringers. A test apparatus simulated stringer deflections experienced during cryogenic loading. This re-created the stringer fractures and provided load, deflection, and strain data to validate structural analysis models. More than 25 stringers were tested.

The cause of the stringer failures was a combination of material being less capable than expected and stresses being greater than expected. The reduction in material capability was attributed to an untypical fracture toughness behavior observed in two lots of aluminum material from which all failed stringers were fabricated. Checking fracture toughness had not been required. The exact metallurgical failure phenomenon was never identified. It was determined that more than half of the approximately 100 stringers on the STS-133 external tank were likely from either of the two suspect material lots. The greater-than-expected stresses were attributed to unexpected assembly stresses that combined with cryogenically induced deflections. Analysis, testing, and inspection provided evidence of several possible sources of assembly stress, including geometric irregularities from the stringer-forming process and stresses from the fastener installation. Analyses also showed that the cryogenically induced stresses were more severe at some stringer locations than others.

All fractured stringers were repaired with sections taken from new stringers. Analyses by the Marshall structural analysts ensured that the repair did not create unintended and detrimental stress concentrations. The Marshall test apparatus demonstrated the effectiveness of the stringer repair.

Working independently but cooperatively with the prime contractor, Marshall engineers enabled the Project Office to present a comprehensive explanation of the failures with unified findings and recommendations to the Space Shuttle Program. STS-133 successfully launched on February 24, 2011, beginning the final mission of Discovery.



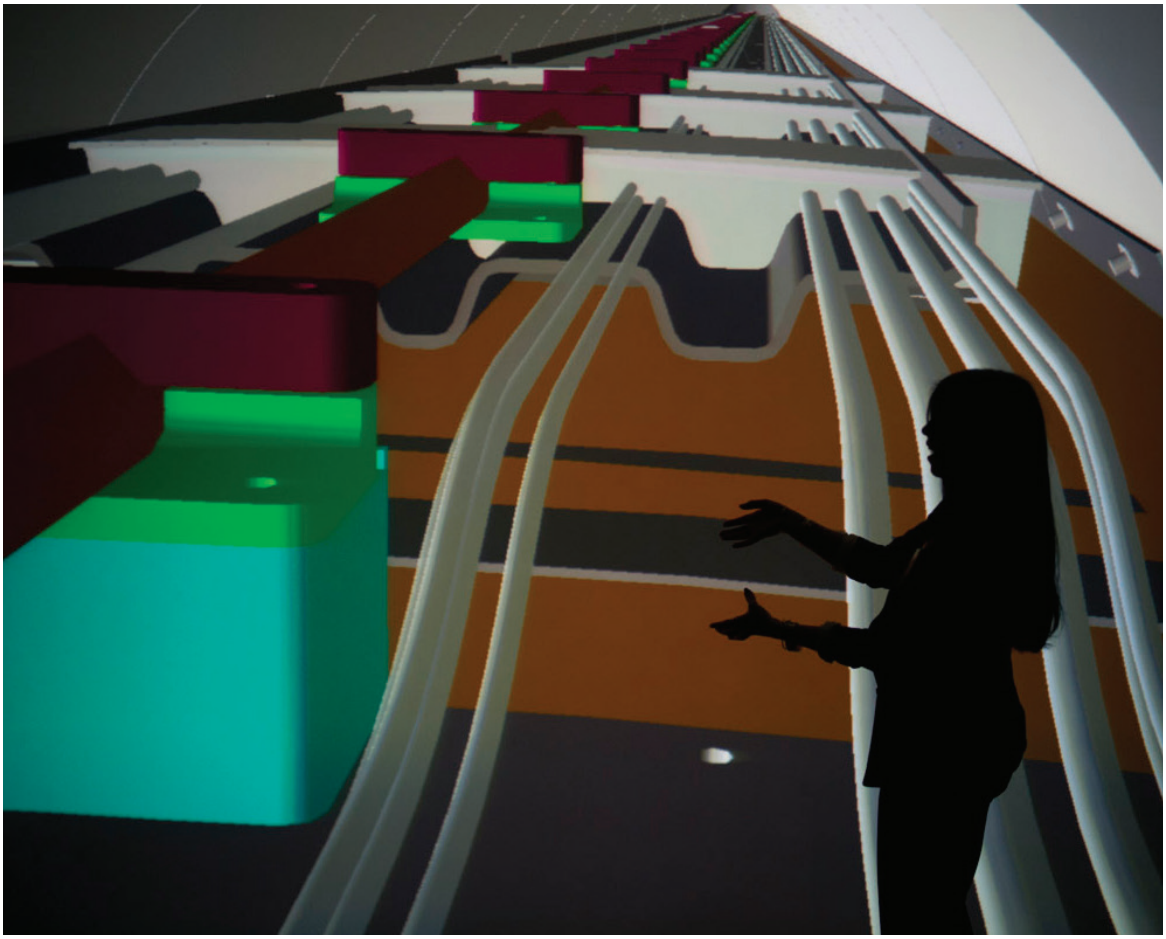
Marshall determined the cause of cracked stringers on STS-133 and evaluated structural integrity of the replacements.

Cross-cutting Discipline Support for Space Systems
Marshall's structural designers and analysts continually balance the physical integrity of the system with the lowest practical weight and most affordable manufacture.

Scaling to meet a wide range of customer requirements, Marshall delivers integrated teams of structural design and analysis engineers for large, complex programs and projects. These range from the Space Launch System (SLS) to single, multi-discipline engineer support for small flight projects or science payload development.

Marshall engineers are experts in state-of-the-art design and analysis software tools to develop and analyze complex 3-D models and 2-D wireframe drawings or schematics. These tools include:

- **Pro/Engineer** — Parametric, integrated 3-D CAD/CAM/CAE
- **Windchill** — Project collaboration and design data management
- **Pro/Mechanica** — Structural and thermal static and dynamic analysis software
- **Hypersizer** — Design, analysis, and optimization software for composite and metallic structures
- **Spaceclaim** — 3-D direct solid modeling software tool for digital prototyping, analysis, and manufacturing
- **Microstation** — 3-D/2-D modeling software and application integration platform
- **NASTRAN** — NASA Structural Analysis software



The Collaborative Engineering and Design Analysis Room (CEDAR) integrates multidiscipline computer-aided design for components of launch vehicles and spacecraft.

Responsive Facilities To Test and Validate Designs

Marshall's comprehensive spectrum of structural test capabilities complements and supports SSDA. These capabilities provide local, easy access for structural design and analysis testing and verification in laboratory and simulated space environments. Other tools include vibration test stands and tables, thermal and thermal-vacuum chambers, axial loading stands, and acoustic chambers. These tools test models and simulations of thermal, strength, dynamics, acoustics and vibration environments of structural hardware.

- **Mechanical Development Facility** (MDF) provides a safe, controlled environment to assemble and evaluate development, engineering, and prototype hardware. It is used for breadboard build-ups, mechanical system checkouts/evaluations, and development of hardware mockups. The MDF can produce rapid prototypes for checking structural fit and assembly clearances when modifying existing hardware.
- **The Mechanical Fabrication Lab** enables structure and assembly research and development, test, and flight hardware. It validates structural design and analysis, and includes quality assurance processes such as in-process inspection, as-built configuration control, hardware traceability and process certification.
- **Small Space Vehicle Landing Stability Facility**, unique to Marshall, tests the stability of lander designs and supports structural design and verification efforts. A scale model of a lander — a Stability Test Lander (STL) — impacts a deck to correlate vehicle dynamics with models and tests whether the design will land safely.

Marshall structure designers and analysts have immediate access to onsite hardware fabrication and test facilities and engineering expertise. This access is a powerful enabler to completing tasks in a timely, thorough manner.

End-to-End SSDA Experience

Marshall is highly capable and experienced in SSDA development of diverse space systems and missions including:

Launch vehicles and in-space stages

- Space Launch System
- Constellation — Ares I upper stage and first stage
- Nanolauncher concepts
- Commercial Crew Integrated Capability (CCiCap) support
- Space shuttle external tank and solid rocket booster systems

Spacecraft and spacecraft systems

- Major spacecraft science observatories such as Hubble and Chandra
- Small satellites and Cubesats
- Lander concepts and demonstrations

International Space Station elements, facilities, and payloads

- Nodes and Multi-Purpose Logistics Module (MPLM)
- Environmental Control & Life Support System (ECLSS)
- Microgravity Science Research Rack (MSRR)
- Sample Ampoule Cartridge Assembly (SACA)

Technology development

- Advanced exploration systems and space technology projects

External customer projects

- DOD, commercial launch providers, automotive industry

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