National Aeronautics and Space Administration

Guidance, Navigation, and Control (GN&C)

Efficient, Responsive, and Effective

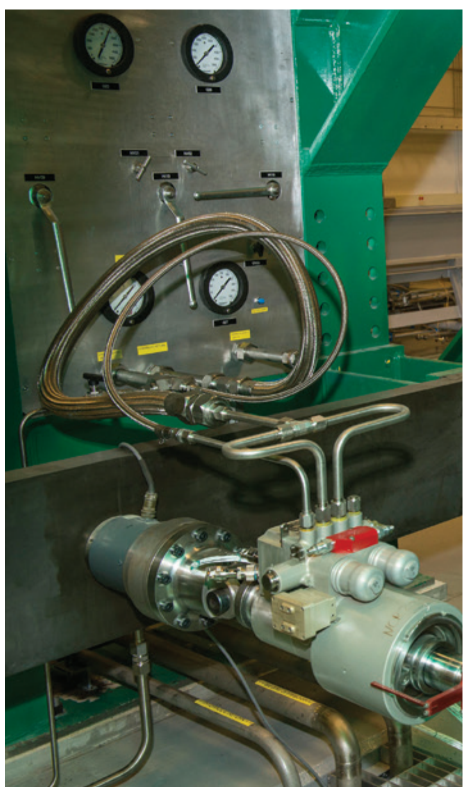
The GN&C capability is a critical enabler of every launch vehicle and spacecraft system. Marshall applies a robust, responsive, team-oriented approach to the GN&C design, development, and test capabilities. From initial concept through detailed mission analysis and design, hardware development and test, verification and validation, and mission operations, the Center can provide the complete end-to-end GN&C development and test — or provide any portion of it — for launch vehicles or spacecraft systems for any NASA mission. Recognized as the Agency's lead and a world-class developer of Earth-to-orbit and in-space stages for GN&C, Marshall is a key developer of in-space transportation, spacecraft control, automated rendezvous and capture techniques, and testing.

The GN&C capability provides:

- **Mission Planning** — orbit and orientation design and planning, launch opportunity, on-orbit lighting and viewing analyses, rendezvous analysis and planning, and mission modeling and simulation.
- **Ascent Trajectory Design and Dynamics Simulation** — ground-to-space path design and optimization, vehicle and propellant sizing, crew emergency abort range (ground) safety analyses, lift-off and stage separation simulation, and complete 6 degrees-of-freedom full vehicle simulation and statistical analyses to ensure safe flight.
- **Guidance** — ascent, on-orbit, rendezvous, planetary approach, and landing — all mission phases.
- **Navigation** — system architecture trade studies, sensor selection and modeling, position/orientation determination software (filter) development, architecture trade studies, automatic rendezvous and docking (AR&D), and Batch estimation — all mission phases.
- **Control** — algorithms, vehicle and control system requirements and specifications, stability analyses, and controller design, modeling and simulation.
- **Sensor Hardware** — selection, closed loop testing and qualification; design, build, and calibrate specialized sensors.

At-A-Glance

Guidance, navigation, and control capabilities will be needed for today's launch and tomorrow's in-space applications. Marshall has developed a GN&C capability with experience directly supporting projects and serving as a supplier and partner to industry, DOD, and academia. To achieve end-to-end development, this capability leverages tools such as the Flight Robotics Lab, specialized software tools, and the portable SPRITE small satellite payload integration environment. The versatile team also provides an anchor and resource for government "smart buyer" oversight of future space system acquisition, helping to manage overall development costs.



Marshall qualifies flight guidance components such as thrust vector control actuators.

Broad Experience with Spacecraft of All Shapes and Sizes

From conceptual mission design to detailed GN&C systems and software development to ground testing and engineering support during the flight, Marshall makes sure the spacecraft gets where it's going. The Center has a long history of designing, developing and testing GN&C systems for launch vehicles, satellites, landers, rovers, and space telescopes, including Shuttle, X-33, Ares, Chandra, and Hubble.

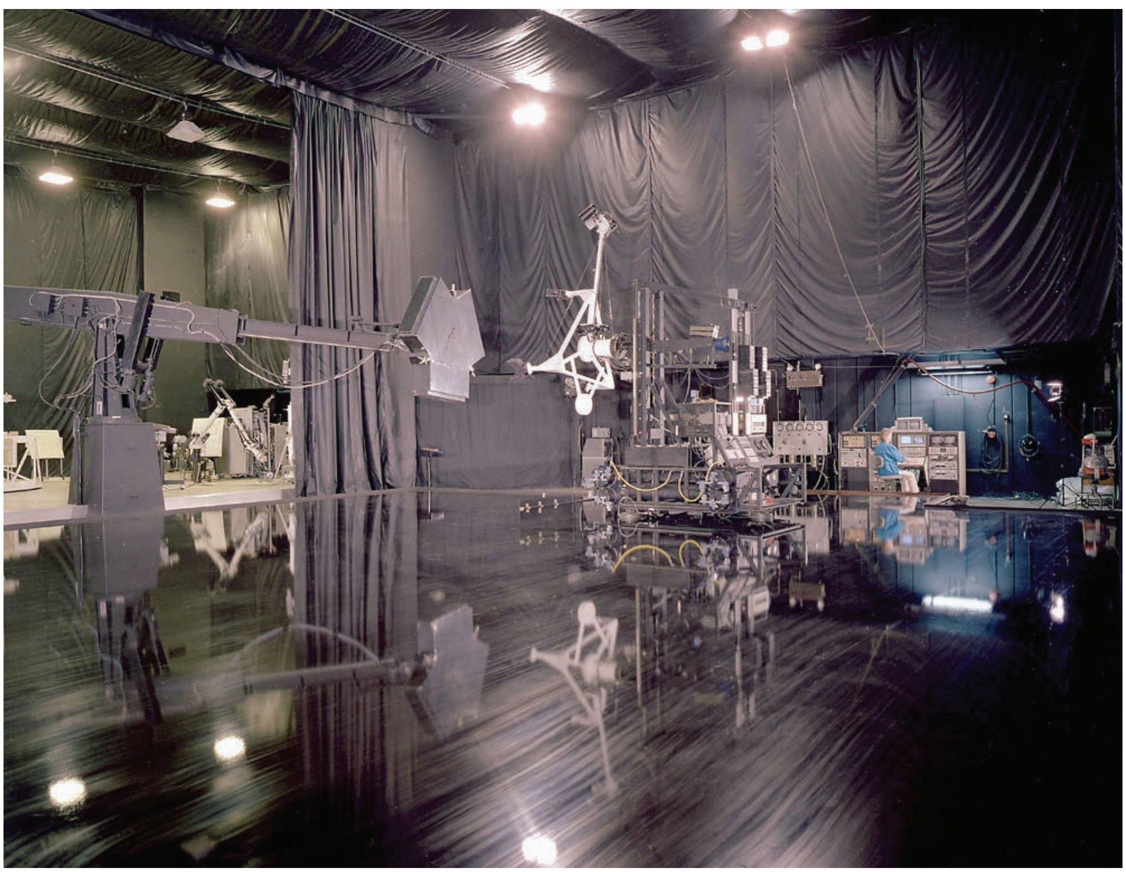
GN&C Architecture for the Space Launch System

Marshall provides critical GN&C components for the SLS — functional requirements and hardware specifications for the SLS Navigation hardware, the Redundant Inertial Navigation Unit (RINU) and the Rate Gyro Assemblies; and thrust vector control electronics. GN&C engineers for SLS are also developing the overall system architecture and all the algorithms that define how the flight software will work, navigate, guide, and control the vehicle. Hand-in-hand with this design work, the entire vehicle is dynamically simulated in extreme detail to drive out any problem areas in the design of SLS as it matures.

Advancing Automated Rendezvous and Docking/Capture (AR&D/C)

Automated Rendezvous and Docking/Capture is the process of bringing two spacecraft together in space. This particular aspect of space travel is particularly challenging, and GN&C has its own specialized algorithms, software, and sensors to accomplish the delicate choreography involved. Marshall successfully flew a video guidance sensor on the space shuttle to test advanced AR&D/C technologies, and provided advanced video guidance system, software, and sensor suite testing for DARPA's Orbital Express. AR&D/C technologies and techniques are critical to existing programs such as the International Space Station (ISS) as well as for future missions such as orbital debris removal, spacecraft servicing, and asteroid exploration.

Very small spacecraft are taking increasingly prominent roles due to their relatively inexpensive cost. Marshall advances in AR&D/C and GN&C enable complex missions to be carried out with these small platforms. For example, the Fast, Affordable, Science and Technology Satellite (FASTSAT) successfully operated six science and technology experiments at low cost. Marshall designed and built the hardware and software, tested and integrated the parts, and supported its operations. Marshall also tested advanced GN&C systems on a small robotic lander, the Mighty Eagle.



The Flight Robotics Laboratory provides comprehensive testing on the world's largest air-bearing floor.

High-Fidelity Testing in Simulated Space Environments

A major component of GN&C system development is testing at all levels, from subsystem components to the fully integrated vehicle. Marshall boasts state-of-the-art testing facilities such as the Flight Robotics Laboratory (FRL) "flat floor" facility and the Contact Dynamics Simulation Lab (CDSL).

The FRL's epoxy floor is a 44-foot x 86-foot precision air-bearing floor, the largest of its kind in the world. A robotic arm is combined with a gantry to provide 8 degrees of freedom (DOF) for simulating relative motion with respect to a fixed target. This apparatus can handle test objects of up to 800 pounds. In addition, a dynamic lighting simulator can simulate the motion and brightness of the sun. These capabilities allow the FRL to test full systems, whole spacecraft, sensors, and cameras. In support of SpaceX, the FRL tested two Proximity Operations Sensors for the Dragon capsule.

Once GN&C system testing is finished, the CDSL tests how the spacecraft handles the contact of docking or capture. With up to a 20,000 lbs. capability, the CDSL can simulate the docking or berthing mechanism motion and interaction in 6-DOF as it would be in orbit. The CDSL has tested almost every U.S. docking and berthing mechanism developed, including extensive testing of the Common Berthing Mechanism and astronaut training for ISS assembly.

In addition to world-class facilities, Marshall also possesses cutting-edge simulation and software tools such as the Marshall Aerospace Vehicle Representation in C (MAVERIC) and the Tree Topology (TREETOPS) Multi-Body Dynamics and Control Analysis tool. MAVERIC is a high-fidelity 6-DOF tool to simulate a space vehicle's launch or flight, including all environmental, propulsion, and aerodynamic forces that it encounters throughout its mission. TREETOPS, and its launch-vehicle-specific relative, CLVTOPS, provide detailed, multi-body analysis of critical events such as lift-off from the launch pad, rocket booster separation, and spent rocket stage separation. These tools simulate the integrated design elements to prove that the vehicle's design can accomplish what the mission prescribes.

Marshall's Mighty Eagle Paves the Way for Future Landers

Marshall and the Johns Hopkins University Applied Physics Laboratory (JHU/APL) are advancing technology for a new generation of small, smart, versatile robotic landers to achieve scientific and exploration goals. NASA's Robotic Lander Test Bed, the Mighty Eagle, conducts test activities to prove the design of this new generation of robotic landers. Marshall and APL engineers conducted studies and tests to aid in the design of this new generation of multi-use landers for future robotic space exploration.

The vehicle is a three-legged prototype that resembles an actual flight lander design. It is 4 feet tall and 8 feet in diameter and, when fueled, weighs 700 pounds. It is guided by an onboard computer that activates the thrusters to power the craft's movements. Marshall is using the Mighty Eagle to mature the GN&C technologies needed to develop a new generation of small autonomous robotic landers capable of achieving the Agency's scientific and exploration goals.

The lander has been through several series of tests, verifying its ability to lift off, hover, transit horizontally across a target area, and descend safely. The GN&C team refined Mighty Eagle's ability to autonomously navigate, including a system recently fitted onto the vehicle for optical hazard avoidance. This will allow the spacecraft to detect potential hazards at a landing site and select a more suitable location before descending.

Mighty Eagle's GN&C system enabled it to autonomously lift-off, traverse, and land successfully.

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